The Elegant Universe
How Do We Learn About What We Cannot See?

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Contents

Overview

The purpose of this unit will be to introduce sixth grade science students to the more accessible concepts of relativity and quantum mechanics. While it is obvious that students at this level of development lack the mathematical skills to be able to comprehend the finer details of these two theories it is true that the overarching ideas present in these theories are things which even sixth graders will be able to appreciate if not fully comprehend. The ideas of quantum mechanics and the theory of relativity will be introduced as part of the study of solar energy. Specifically quantum mechanics will be introduced as students study how the sun produces the energy, which it sends to the earth, and relativity will brought in as students discover how the gravitational effects of the sun hold the solar system together.

The students will learn first about the origin of the solar system, the sun, and its attendant planets, asteroids, comets, meteors, and so on. This will be followed by an in depth study of the sun and its primary role in the solar system. This would include the sun's means of producing energy, how that energy is transferred from the sun to the earth and how that energy is absorbed, reflected and distributed throughout the earth. Subheadings would include: shadows and how they move, (movements of the earth relative to the sun), solar energy, color and absorption, and practical uses of solar energy.

While it is obvious that a full blown study of either of these theories would be pretty much impossible to undertake at the sixth grade level, basic ideas of both of these theories could be added to the curriculum like the chocolate chips in cookies. Although it can be argued that the cookies could be just fine without the chips most people would agree that their addition makes something that is already good even more enjoyable. That is what I have in mind for this unit. I want to spice up the curriculum with ideas that are so wonderfully unusual that my students would not be able to resist wanting to know more about these subjects in particular and science in general.

Rationale

Students at the sixth grade level have very little concrete knowledge of science in general and or the people who were responsible for the great discoveries, which have made our modern civilization possible. For example, if asked which is larger the earth or the sun most students would tell you the earth. Their ability to conceptualize the effect of distance on a very large object like the sun making it appear small is generally not present. In fact a significant number of the students that I teach might not be sure that it's the earth that revolves around the sun instead of the other way around. When asked if the earth is moving they will tell you no, their reason being that they cannot feel it. The students who will study this curriculum are basically mainstream pre-adolescents who do not grasp the abstract with any great facility. The majority of these students have difficulty with mathematics at any level.

The desired outcome of the sixth grade science course is to begin to correct the aforementioned problems and to help the students to make the transition from the concrete to the abstract. The ideas found in relativity and quantum mechanics could prove to be very beneficial in this endeavor. By any measure the ideas inherent in these theories are largely counter intuitive and yet fascinating for their very strangeness. It is hoped that the introduction of these concepts would capture the student's imaginations in such a way that they would be able to exercise and develop that imagination in the course of their daily studies. One of Einstein's perhaps lesser-known but no less important statements is this; "Imagination is more important than knowledge." While it can be argued that Einstein had a great deal of both knowledge and imagination and that our students have very little of either the need to develop both is of paramount importance.

In the period prior to the Renaissance what constituted the nations of Europe were a group of largely feudal thiefdoms. The hallmark of these countries was primarily oppression, poverty, disease, and stunning amounts of ignorance from the monarchs to the common people. At the same time, in far away China and India, civilizations were flourishing which far surpassed anything that could have been found in Europe. The Europeans however, made a great discovery, not all at once but gradually. They developed a method of investigation and problem solving that today we call the scientific method. This tool was so powerful that it allowed this collection of ignorant backward nations to zoom ahead of far older and more technologically developed countries to become the dominant powers of the world until the end of the First World War. While it could be argued that the scientific method was not the only advantage they ultimately enjoyed, a very good case could be made for the idea that it was of primary importance. Since this method of investigation has proven to be such a powerful means of acquiring information it is of the utmost importance that students have a very clear understanding of it and have ample opportunity to practice it in the classroom. It is hoped that this will then become an innate aspect of their mental processes so that they can call upon this resource at any time. Using the Scientific Method, students will improve their critical thinking skills by confirming the more concrete ideas inherent in the unit. They will then be asked to make guesses about how scientists are able to make determinations about things, which cannot be seen. (see classroom activities, p)

Arguably one of the greatest and most useful discoveries brought about through the scientific method is the periodic table of the elements. Starting over two hundred years ago with Demetri Mendelev and proceeding in fits and starts up through the second world war when Glen Saeborg rearranged the actinide and lanthanide series, the periodic table has become one of the most widely used tools in all of science. The periodic table gives a logical orderly arrangement of the elements grouping them in such a way that once the basic principles of its use are understood great amounts of information may be extracted from it.

My goal for these students is that they will learn the fundamental principles of scientific investigation. For example, the students will investigate using the scientific method, the position and importance of the sun relative to the earth and the rest of the solar system as well. As each important characteristic of the sun and its role is examined students will be introduced where possible to the more accessible aspects of the quantum theory and relativity. Students will be given the opportunity to expand their levels of understanding by having the opportunity to synthesize the principles of these theories in conjunction with the more concrete aspects of the sun.

It is important for students to understand not only the facts and the theories of science but how it was and who it was that was responsible for these major scientific advances and developments. If most sixth graders were asked to name a scientist pretty much all of them would be able to name Einstein and some might even be able to repeat his famous formula. There are literally dozens of imminent scientist whose discoveries are foundational to the world in which we live which no one can even name much less know what it is they did.

For example, when discussing the fact that it's the sun's gravity that holds the planets in orbit and thus creates the solar system, the students could learn who it was that discovered the law of gravity and how he did it. Learning about the man and the times in which he lived and the conditions under which he made his great discovery would enable students to see that it was real people a lot like them who made these great advances in science. It is known that Newton lived on a farm. Much to his father's dismay, Newton was not very good at being a farmer, so he was sent to school. He later went on to Cambridge University in London, where he studied among other things mathematics. In the mid seventeen hundreds, while Newton was in college, the plague swept through Europe. People fled the cities to the countryside to avoid catching the disease. The university was closed and Newton returned to his family farm. It was there over the next 18 months that he discovered the spectral nature of light, invented calculus, set down his three laws of motion, and discovered how gravity worked. As the story goes, this all began as Newton saw an apple falling to the ground and wondered if it was not the same force pulling the apple to the ground that held the moon in orbit around the earth and the earth in orbit around the sun. Newton started out just like any of us. What set him apart was that he trained and disciplined his mind, had keen powers of observation, and time to think and let his creativity develop.

People have worshiped, studied, and wondered about the sun for thousands of years. To the Egyptians the sun was of paramount importance and their god Ra was of course the sun god. The sun was revered as the source of life for millennia by numerous cultures and peoples. For example, on the other side of the world from approximately 1000 B.C. to 500 A.D., there was a culture in what is now northern Peru called the Moche. This was a group of people known mainly for their great monumental architecture. Among these great structures was that of the Great Pyramid of the Sun. This structure though not as sophisticated as the ones built by the Egyptians was never the less a stunning achievement. It is estimated that this structure contained over 125 million mud bricks. This is an indication of the importance that the Moche placed on the sun. The amount of resources that would had to have been devoted to the building of this structure would have been enormous, not only in man power, but also in wealth. Many other things could have been done with these resources but the Moche chose to use them in this manner. If you want to know the real values of any culture, one could examine this by seeing how they used their resources. It is my hope that with the introduction of these topics, it can be hoped that students will have gained an appreciation for the archaeological and historical aspects of science.

By the early renaissance people were wondering what exactly was the source of the sun's enormous power. Some believed that it was burning yet once its actual dimensions had been calculated, the scientists of the day were astute enough to know that if the sun was made of something combustible like wood or coal or some other substance it would have burned out long ago. It was not until the beginning of the twentieth century that scientists began to realize that the reactions that powered the sun were nuclear in nature and not chemical. The nuclear reaction that powers the sun is possible only because of the sun's immense gravity. The gravity of course, is in direct proportion to the total mass present. The sun possesses approximately 99 percent of all the mass in the Solar System. The planets, comets, asteroids, meteors, and anything else that might be present, constitute only about 1 percent of the Solar System. This is a region of space that physicists refer to as gravitationally collapsed in contrast to the vast, open regions of inter-galactic space, which are not. Exactly what caused this collapse to take place is still subject to much debate. Gravity, of course, plays a part but something has to trigger the process. What this something is, is still not clearly understood. Some scientists believe that the shock wave from super nova may be sufficient to begin the collapse of a nebular cloud into a star and its attendant planets. Other scientists believe electro magnetic forces that exist in the inter-stellar gas and dust of space may be factor. However, a complete explanation of this process is something that has eluded those who are searching for it. In any case, in the end, it is the force of gravity that makes nuclear reactions possible.

As our awareness and understanding of our atomic theory grew it finally became clear that the sun was converting matter into energy according to Einstein's E=mc squared formula. Even at this point however, the precise set of reactions were still unknown. It was not until the 1930's that Hahns Botha (A German physicist who had immigrated to the United States and was teaching at Cornell University) was able over a period of three weeks to develop the mathematical calculations, which explained exactly how the sun's power was produced. This work was so monumental that thirty years later he received the Nobel Prize in physics for his achievement. It is worth noting here that the reason Mr. Botha was in the United States was because he was Jewish and in the 1930's the Nazis were busy persecuting anyone of Jewish background and so Hans Botha left Germany and came to the United States. This sort of brain drain had serious effects when the Germans tried to develop their own nuclear weapon. They had driven out so many of their best nuclear scientists that it was the United States, which had given a home to these scientists, that developed the world's first nuclear weapons. One can only wonder how the history of the world would have been different if Germany had not had this program of persecution against the Jews.

One of the most significant applications of the scientific method occurred with what is now known as the Michaelson-Moreley experiment. This took place in the 1880's at Case Western Reserve in Cleveland, Ohio. Albert Michaelson was perhaps the best experimental physicist of his day. His ability to design and build experiments to test scientific theory is still legendary. In this particular case he and his assistant, Morley, set out to prove the existence of the ether. Since the time of Aristotle it had been believed that there was a substance, which filled all space and was the medium by which energy from the sun was transmitted to earth. It was known in the 1880's that light could be described as a wave. It was thought that a wave could not exist unless it had something to "wave through." For example, without water there could be no ocean wave. Without air, there would be no sound waves. It was also known that the speed at which a wave traveled depended directly on the density of the medium through which it travels. Sound for example, travels faster through water than it does through air and faster yet through solids than it does through liquids. It was known at this time that the speed of light was very fast. Michaelson himself had conducted an experiment to measure the speed of light and had come up with a very accurate answer. At the same time scientists believed that this medium which carried electromagnetic radiation from the sun to the earth could offer no resistance to the movement of the planets that is the planets had to pass through it with no resistance. Had there been any kind of friction or resistance at all the planets, would have gradually slowed in their journeys around the sun and spiraled ever closer until they fell into the sun. Since this was clearly not happening and since the scientists of the day firmly believed in the existence of the ether it had to possess two rather contradictory characteristics. That is it had to be extremely stiff or dense in order for light waves to travel so rapidly through it and it had to be perfectly frictionless for the planets to be able to travel in their journeys around the solar system unabated.

With all of this in mind Michaelson prepared his now famous experiment. He had developed a device called an inferatomator which worked basically like this; it would split a light beam into two parts sending them at right angles at each other to a mirror to be bounced back to the point at which they were originally divided. If both light beams took precisely the same amount of time to travel outward and back no interference pattern would be produced. If however, one light beam traveled slower than the other an interference pattern would be produced. When the experiment was run the results were conclusive, there was no ether. Neither Michaelson nor Morley believed the results of their experiment and were convinced that they had made some error. They adjusted their equipment and tried again. In fact they tried it over and over again, hundreds of times yet each time it gave the same result, there was no ether.

Scientists around the world duplicated the Michaelson and Morley experiment and got exactly the same results, but so powerful was the paradigm of the ether that it took many years before most of the scientific world was convinced that the experiment was accurate and no ether existed. It is worth noting that for the next fifty years Michaelson considered this to be his greatest failure. Even though this is considered to be one of the greatest experiments ever conducted, if you were to ask most students who Michaelson and Morley were, they would have no clue as to who they were or what they did.

I see this lack of knowledge of great scientists and their achievements as a serious problem in our educational system. I believe it to be ultimately self-defeating to simply try and stuff students full of factual data. No matter how useful the data may be, when it is divorced from the people and circumstances under which it was acquired it loses a great deal of its meaning and significance. For example, the fact that Madam Currie died from cancer that was brought on as a result of her work with radium and polonium, brings another whole level of meaning to this discovery. Students should know that many of these great discoveries came at a very real cost to the people who made them. So as I introduce the ideas of quantum mechanics and relativity to my students I intend to do it not merely as factual information but in the form of narrative and story. For example, one of the fundamental principles of quantum mechanics is Schroedinger's equation for wave function. By using Schroedinger's equation, scientists can find the wave function, which solves a particular problem in quantum mechanics. Unfortunately, it is usually impossible to find an exact solution to the equation, so certain assumptions are used in order to obtain an approximate answer for any given problem. However, when there is no force acting on a particle, potential energy is zero and the Schroedinger equation for the particle can be exactly solved. The solution to this "free" particle is something known as a wave packet. Wave packets therefore, can provide a useful way to find approximate solutions to problems which otherwise could not be easily solved. How it was that Schroedinger discovered this is perhaps counterintuitive to the way most people would think that scientist work. If asked to describe the situation and conditions under which scientists make their discoveries most students would probably give a description that included laboratories, lab coats, lots of equipment such as test tubes and computers. No one, unless they knew the story, would describe what had actually happened. Schroedinger was unhappy with the progress that was being made in discovering the behavior of sub-atomic particles and so took it upon himself to try and break this impasse. He left his home in Vienna, drove to Paris, picked up his mistress, and went off to a Chalet in Switzerland where for the next few weeks he labored on the mathematics, which became Schroedinger's equation. In addition to the mistress he had two pearls, one of which he put into each ear so he could work undisturbed and so it went from mistress to mathematics and back again. The reality of how Schroedinger's equation was actually discovered can be said to be far more interesting than most people would suppose.

Quite honestly it is my opinion that one of the reasons students seem to have a hard time remembering the facts that we present to them is because we present them facts. While this may be the most "efficient way to deliver a given set of data" it is in the long run not the most productive way to teach it. I think it could be effectively argued that Schroedinger's equation would be remembered with greater clarity and by a greater percentage of the students if it were presented in the context in which it occurred as opposed to a mere set of facts about the behavior of sub atomic particles. Almost everyone knows the story of Archimedes' famous bath experience and his sprint "oh naturale" from his house to the palace shouting "eureka." It is therefore, then easier to remember the scientific principle that went with it, displacement and buoyancy. It makes much greater sense to teach the other foundational principles of science in the context of the people and the circumstances under which they were discovered.

Objectives

As previously stated I am not so much interested in students learning a set of facts as I am that they learn the process by which science unfolds the mysteries of the universe. While a solid factual base of information is necessary and useful for more advanced explorations in science as well as in other areas I do not believe that this can be the entire goal and objective. So when the students are studying the sun and how it produces energy I want them of course to know that it is a nuclear reaction called fusion, that it takes place only under extreme high temperatures and pressures, that it occurs in nature because the force of gravity and the nature of matter makes it possible. They should know that we have been able to reproduce this process to a limited extent here on earth and that scientists are trying to be able to produce a controllable fusion reaction which would be able to supply all the energy needs of the planet forever. This would be the logical place to introduce some of the ideas of quantum mechanics as a logical step in studying the atomic structure, which makes fusion possible. They should know about the Manhattan project because this is where our use of nuclear power began even though that was for destructive purposes. They should know that in this country approximately twenty percent of the electricity we use in our homes, businesses and schools comes from a reaction called fission (the splitting of large heavy atoms) and that this technique which is now used to make electricity was an outgrowth of that same Manhattan project.

A very interesting discussion could be had concerning whether nuclear weapons and nuclear power plants have thus far been harmful or helpful. In particular an interesting discussion and or debate could be had with my students over whether a third world war has been averted due to the presence of nuclear weapons. The twentieth century began on a note of optimism. There was a general belief in unlimited progress as rapidly advancing technologies were brought to bear on the human condition. At the same time, however, in Europe, intense nationalistic rivalries began to develop and worked themselves out in such areas as who could build the fastest ocean liner, who could construct the biggest battleship, and of course, who had the best army. The fact that all the heads of state of all the major combatants in World War 1 were related, should have been a mitigating factor. But as it turned out it was not. And so, when Prince Ferdinand

and his wife were assassinated in the country of Serbia, demands were made, armies were mobilized, threats and counter-threats flew back and forth, and in very short order, millions of men went off to fight and die in a war that need never have occurred. The end of the war was concluded in the Treaty of Versailles that the great British economist, John M. Keanes had pointed out, was only going to create the conditions for another world war that would be far more deadly and disastrous than the one that had just concluded. He was roundly denounced for his views, called all sorts of names and was generally ignored. The fact that his predictions turned out to be correct like that of a biblical prophet, seems to be a little footnote lost in the pages of history. Twenty years later, the world found itself engulfed in a war that Keanes had predicted. But at the end of that war, nuclear power was for the first time put into the hands of humans. For the first time in human history if a major war broke out it would be the leaders of the nations, not the soldiers in the field who would die first. This I believe has had a rather calming effect on leaders who would otherwise have resorted to war in the past.

As we discuss the sun's means of producing power and the discoveries that were made in the process of unlocking these secrets it would be important for the student's to know who was involved and how the discoveries were made.

I would like my students to know that it is the sun's gravity that organizes the solar system causing the various planets with the attendant moons as well as the comets, asteroids, and so on to revolve around it. They should know that it was Isaac Newton who first gave us an explanation and understanding of how gravity worked but they should also know that he was building on the work of other persons who went before him like Galileo, Copernicus, and Kepler. As the students learned about the sun's pivotal role in the solar system and Newton's idea about gravity I would then bring in the most famous scientist of all time, Albert Einstein. They should know that Einstein's view of gravity is completely different from Newton's view. That Newton saw gravity as a force, Einstein understood gravity to be the warping and bending of space and time as a result of an object's mass. This description was Einstein's Theory of General Relativity, first published in the year 1915. General Relativity says that the three spatial dimensions and the dimension of time are bent and warped by matter. The more matter there is the greater the warpage. As a result of the warpage caused by the earth for example, the moon travels around the earth due to the greater warpage caused by the sun the earth and moon together travel in a curve through four dimensional space time. It was only four years after Einstein published his concept of gravity that British astronomers were actually able to measure the warping that his theory predicted. The New York Times put it this way, "Lights all askew in the heavens, stars not where they seemed or were calculated to be, but nobody need worry." It was because of this new understanding of gravity that scientists were now able to make real predictions about how the universe might be and essentially made cosmology a science. This is where relativity could be introduced naturally as an outgrowth of the study of gravity and how the sun dominates the solar system because of its huge gravitational field.

Strategies

As we begin the section on solar energy I will be introducing my students to the concept of the solar system as a whole with the sun being the dominant player in it. We take a brief journey through the planets describing the location, basic characteristics such as, period of rotation, period of revolution, size, etc.. We will then focus in on the earth and what makes it unique among the planets of the solar system, life being the obvious answer. This will lead to a discussion of why there is no life on the other eight planets of the solar system. The students will come to see that the amount of energy each planet receives from the sun is crucial in determining whether life can exist on its surface or not. The students will be brought to the point where they understand that the earth is in perfect position in terms of its distance from the sun to receive just enough energy so that it does not overheat like Mercury or Venus nor become cold and arid like Mars.

We will then go into how it is that the sun produces the energy that it does, how long it's been doing it and how long it will continue to do it. We will discuss why it is possible for the sun to produce such huge quantities of energy for such a long time and this will lead us to the conversion of matter into energy as in Einstein's formula E=mc squared. I will teach them that the formula states that matter and energy is the same thing and that the reason that a small amount of matter produces such a large amount of energy is "c squared" and what it is. I will want the students to know that the reaction which powers the sun is called fusion and that for this to occur the core of the sun must be very hot, approximately 15 million degrees Celsius and have a million atmospheres of pressure. They will learn that this is only possible because of the immense gravity of the sun.

As we study the reason for the sun's huge gravitational field (that being its enormous mass) I can easily introduce the student's to Einstein's concept of gravity as a warpage of space-time. I will explain to them that the reason the planets orbit the sun is that the sun creates a "depression" creating a curvature of space and that the planets follow this curvature rather like a marble in a funnel. I will also use overhead transparencies and diagrams which use the rubber sheet analogy , which is that space can be compared to a large rubber sheet rather like the surface of a trampoline and when a massive object is placed on the sheet it creates a depression in the sheet which radiates in all directions.

This creates "downhill" slope from the furthest point of the rubber sheet to the massive object the closer we get to the object the steeper the downhill becomes. This explains why the planets, which are closer to the sun, revolve at a higher rate of speed. They are on a steeper part of the sheet and why a planet like Pluto takes over two hundred and forty years to make one complete revolution. As we discuss the effects of a large massive object on the shape of space I can also explain to the students that time itself is changed by the presence of this mass. The more massive the object is the slower time goes because space is curved to a greater extent by this greater mass.

Once we have completed the discussion centering around the effect of the sun's mass on space and time we will then go back to how the sun produces energy where I will explain to them in the simplest possible form how fusion takes place, that being the combining hydrogen nuclei to produce helium and give off energy. It is in the discussion of what a hydrogen nucleus is (a proton) that I could explain to them that protons are made of even smaller things called quarks. It is at this stage that I will do my mystery box exercise with the students. I will give the students three boxes; one containing marbles, one containing sand, and a plastic bag full of water. They will then be asked to determine to the best of their ability what is inside the box without actually opening it. (See classroom activities for details) I will then relate this activity of determining something they could not see to what physicists do with an atom smasher, by using this tool scientists can determine what is inside something that is too small to be seen. It is in the course of this discussion about quarks and other sub-atomic particles that some of the characteristic features of quantum mechanics could be mentioned. Things like the "Uncertainty Principle," the actual shapes of electron clouds, the wave particle duality of light and matter and finally quantum tunneling.

One of the more common and glaring errors about the nature of matter that is found even in science textbooks is the way in which electrons orbit the nucleus. Even the word orbit is obsolete. The fact of the matter is that electrons do not orbit. They are merely found in one place as opposed to another and that we cannot say with certainty which of those places it will be (The Uncertainty Principle). I will use the quantum diagrams for things such the 1s, 2s, 2p, 3s, 3p, 3d which are probable locations where one can find an electron. I would then explain that the reason students see pictures in their textbook that show electrons looking like little planets orbiting the sun is that it's much simpler for most people to think of atoms in that way than in the way they really are.

I am convinced that if these ideas are presented to my students in a clear and logical fashion, with lots of opportunities to examine diagrams and have discussions, they will be able to understand these concepts. This will hopefully better prepare them for their future and more advanced studies in science as well as stimulate their imaginations and curiosity which is perhaps of even greater importance.

Classroom Activities

As previously mentioned in the strategy section, when explaining how scientists are able to study things that they cannot see and learn about them, the students will do the "black box" experiment. Each lab group will be given three boxes; one containing sand, one containing marbles, and one box containing a plastic bag or balloon full of water. The boxes will be filled approximately half way with each substance. This will cause certain and different sounds to be produced as the students turn or shake the boxes, which will be their best clue as to what is inside. After the students have had ample opportunity to thoroughly examine their boxes, each group will have a reporter to explain what they believe is in each box and state their evidence. Once they have completed their presentation and stated their conclusions, the groups will open their boxes. This will then be related to what particle physicists do when exploring the sub-atomic particles of the atom.

As stated in the objectives I feel that is important for students to have a sense of the flow and development of scientific thought and exploration. To this end, I will have the students create a timeline, beginning with the Golden Age of Greece, and men like Aristotle, Archimedes, Domocritus, concluding with present day scientific discoveries. The timeline will be designed in such as way with the name of the scientist and a brief description of his or her discoveries will be included. I will give each student the name of a scientist to research and tell them to use encyclopedias, the internet, etc., to find out who this person was, when they lived, how they made their discovery and why their discovery was important. They will then be asked to present their information to the rest of the class and each student will be responsible for entering their information on the timeline chart. This chart will be posted in the classroom and referred to consistently throughout the year.

To help students get a grasp of the relative size of the objects in the solar system the students will make a scale model of the sun and the nine planets. The students will be asked to draw a scale model of their particular planet where a thousand miles is equal to one millimeter. Students will be assigned to a group and each group will be assigned a certain number of planets to draw on poster board using the given scale. The end result will show my students that the size of the planets vary greatly but that compared to the sun they are all quite small. This will give them a better sense of why the sun is the center of the solar system and that everything revolves around it.

To help students further understand the warpage of space due to the sun's mass we will use a large funnel (approximately thirty inches in diameter) into which we will project marbles from a spring launcher so that the marble will be at the very outer most perimeter of the funnel. It will be explained that it is the curved shape of the funnel that causes the marble to go into a circle. The students will be able to observe this. It will then be compared to the movement of the planets around the sun due to the curvature of space-time.

To help students to gain a better understanding of the "Uncertainty Principle," we will use a game involving dice. Each group of students will be given a die for each student and a quantum diagram showing possible locations of electrons for particular atoms. The students will then number the positions and then roll their dice. They will then record how many times the dice must be rolled in order for them to come up with the number that they had chosen. It will be explained that this is similar to the difficulty in predicting at any particular time exactly where an electron might be.

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Appendix A: Content Standards for the Pittsburgh Public Schools.
The following standards are addressed in this unit.

Reading, Writing, Speaking and Listening:

1. All students use effective research and information management skills, including locating primary and secondary sources of information with traditional and emerging library technologies.

3. All students respond orally and in writing to information and ideas gained by reading narrative and informational texts and use the information and ideas to make decisions and solve problems.

5. All students analyze and make critical judgments about all forms of communication, separating fact from opinion, recognizing propaganda, stereotypes and statements of bias, recognizing inconsistencies and judging the validity of evidence.

6. All students exchange information orally, including understanding and giving spoken instructions, asking and answering questions appropriately, and promoting effective group communications.

Mathematics.

1. All students use numbers, number systems, and equivalent forms (including numbers, words, objects and graphics) to represent theoretical and practical situations.

2. All students compute, measure and estimate to solve theoretical and practical problems, using appropriate tools, including modern technology such as calculators and computers.

3. All students formulate and solve problems and communicate the mathematical processes used and the reasons for using them.

7. All students evaluate, infer and draw appropriate conclusions, from charts, tables and graphs, showing the relationships between data and real-world situations.

Citizenship

8. All students demonstrate that they can work effectively with others.

Science and Technology.

1. All students explain how scientific principles of chemical, physical and biological phenomena have developed and relate them to real-world situations.

2. All Students demonstrate knowledge of basic concepts and principles of physical, chemical, biological and earth sciences.

3. All students' use and master materials, tools and processes of major technologies, which are applied in economic and civic life.

4. All students explain the relationships among science, technology and society.

5. All students construct and evaluate scientific and technological systems using models to explain or predict results.

6. All students develop and apply skills of observation, data collection, analysis, pattern recognition, prediction and scientific reasoning in designing and conducting experiments and solving technological problems.

9. All students demonstrate basic computer literacy, including word-processing, software applications, and the ability to access the global information infrastructure, using current technology.