Researching The Unseen

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Overview

In the fourth century BC, the Greek philosopher Democritius suggested that there had to be some basic building block of matter. He reasoned that you could not keep breaking down matter indefinitely. There had to be a final indivisible particle, which he called "atomos." The search for that particle has continued since then and will continue. Now what is believed to be the ultimate building block of matter is indeed almost nothing. Strings are incredibly small vibrating parcels of energy. Researchers finally believe that they have reached that indivisible particle. Just like Democritius scientists have had to reason their ideas as proof is very difficult. Through this unit I hope that students will appreciate the efforts of the kind of research which requires a belief, strong mathematical skills and less direct experimental evidence. The development of string theory is an example of the development of a new mathematics, which only partially helps to solve the difficult equations; an ability to conceptualize something that can't be seen; and experimental data obtained from the furthest reaches of the universe and expensive, controversial particle accelerators. By tracing the history of these developments students will have a better understanding of these incredibly small basic particles of matter, as well as an appreciation of the difficult task of researching in this area. Since this unit is designed for gifted students it is appropriate to expose them to the challenges of this type of research and provide insight into the skills needed to be a researcher. These students are taking first level chemistry in high school and have had biology in 9^{th} grade and are taking at least algebra II concurrently with the chemistry course. They will not have taken any physics and so have limited knowledge of electricity and magnetism.

Rationale

Typically when high school chemistry students study the atom, their main focus is the electrons and the ability of the nucleus to hang onto these electrons. In middle-school science students have learned about the composition of the nucleus and are generally presented with the Bohr model. This is the model of the atom where the nucleus is like the sun and the electrons travel around the nucleus like the planets in our solar system. In high school students are taught the quantum mechanical model of the atom and are introduced to the basic concepts of quantum mechanics and so have a more accurate view of the behavior of electrons. But they are left with the idea that the electron, proton and neutron are the smallest sub-atomic particles. Quarks have been known since 1968 and it is time that students have a more current version of the building blocks of matter.

In my course I teach nuclear chemistry so that students will have a better understanding of the stability of the nucleus and the interaction between the neutrons and protons. To further their understanding of what is happening, I would like to introduce the sub-particles that make up the neutrons and protons, as well as the weak and the strong force. This explains how the nucleus stays together rather than flies apart as predicted by electrostatic repulsion. Within the nucleus are incredibly strong forces and the study of the production of the energy produced in a nuclear reaction allows students to better understand these forces. Nuclear energy shows the relationship between matter and energy or should one say the equivalence of the two. A formula emblazoned on a T-shirt does not do it! To better understand how particle accelerators work it is important that students understand both nuclear fusion and fission. They always ask why certain elements have a mass written in parentheses. Through nuclear chemistry I am able to explain the creation of these elements, discuss nucleus stability and introduce particle accelerators.

String theory is very difficult to understand as we are presented with a "particle" which is too small for anyone ever to detect; has more dimensions than we can ever imagine and somehow manages to interact in such a way that we have solid matter. Pretty amazing! Students need to appreciate the difficulty of explaining such particles as well as trying to research their existence and properties. By a historical look at the steps taken in the search for this theory and an understanding of each obstacle and the breakthroughs, students will better understand how research is conducted. They need to know how long it takes and the small steps that build to make eventual progress. By looking at such recent research, students will be able to put themselves in the shoes of the scientists who have conducted this research. When we look at research from much earlier periods, the students find it difficult to appreciate the leaps of intellectual reasoning of these scientists, since they, the students already know what was discovered and take it for granted. Understanding what it takes to do research and having a historical perspective is one of the standards in science for the Pittsburgh Public Schools and is also a standard advocated by the National Endowment for the Sciences.

Much of the research into string theory has involved the development of new mathematical theories to solve the problems. Not all the tools have been developed yet. There is also a heavy dependence on computing power. This is the new way of doing research or theoretical research. Since I teach gifted students, there are many students in my classes who may go onto science and research. They should take inspiration from scientists who were often young when they made their breakthroughs.

An understanding of matter comes from looking at how matter formed after the Big Bang. This requires looking at light which is arriving from the edge of the Universe, as we know it. This shows the interdependence of all branches of science and the need for students to have a broad based education in all sciences rather than an early and narrow focus from specialization. An historical approach shows how knowledge builds on many fields and investigations. Students need to be able to read about any branch of science and understand it. Hopefully they will be encouraged to continue on and take physics in high school. Earth Space science is only offered at a very basic level at my school and my students are unlikely to take it. By looking at some of the research they will be exposed to a small part of the fascinating world of cosmology.

Any evidence which can be found to support string theory has come from data obtained from high speed particle accelerators. We need even bigger ones so that the particles can have even more energy. The federal government recently stopped construction on the next super particle accelerator in Texas. Fifty million dollars had already been spent. Our students will have to vote on these issues and need to know the reason for the research so that they can put a value on it and make more informed decisions.

One way to afford a particle accelerator is through shared support by many nations. This international view seems to be a trend in other areas and so should apply to science. What is unaffordable for one nation can be affordable when spread over many government budgets. The history of science also shows that research is an international endeavor and that results obtained by scientists in other countries, can be applied and expanded by researchers in another. The scientific community is indeed international. Students need to be prepared to accept and join such a community.

The topic of string theory and particle physics is very complex, yet many of those researchers have felt very passionately about their subject matter and have felt compelled to describe these difficult concepts to the general public. There are many such books written: Stephen Weinberg, a Noble Prize winner for his work in unifying two of the fundamental forces, writes in "Dreams of a Final Theory" advocating continued research into the fundamental particle of nature; Brian Greene, describes in "The Elegant Universe" string theory and the driving force to find a unified theory; Murray Gell-Mann, another Nobel Prize winner describes in "Quark and the Jaguar" the complex and the simple both in particle physics and in the biological world. These books make the authors accessible to students. Through reading excerpts from these books students feel the passion that these scientists have for discovery, their ability to communicate and communicate extremely technical and obscure concepts. At times they even admit to not knowing all the answers. These authors also describe how they developed a passion for science as youngsters. The books show that these exceptional men have a broad interest and knowledge of many subjects. In other parts of my course I have my students read Richard Feynman's description of the one thing that you should know from science - that matter is comprised of atoms. I also have my students read a few chapters from the "Double Helix" in order to see the role that hydrogen bonding plays in the matching of the bases and the reason for duplication of the DNA code. I also use this reading to discuss the creative process. The readings are great exposure for the students to some of the brightest minds in modern science.

The Standard Theory

There were three reasons to suggest that neutrons and protons were not elementary particles. Protons and neutrons behave like small magnets. Quantum mechanics can predict the strength of the magnetic properties of an elementary particle but the proton and neutron behaved like stronger magnets than was predicted. After World War II, the Stanford Linear Accelerator Center (SLAC) was built to probe protons and neutrons in a manner similar to Rutherford's discovery of the atom. Early experiments supported the belief that the protons and neutrons were indeed composite and not point like, but the probes (electrons) were not energetic enough to allow experimenters to determine the actual strength. The particle accelerators discovered a large number of particles similar to the neutron and proton. These particles were called collectively "hadrons". So many particles suggested that there had to be some simpler constituent particle. Finally in 1968, a new set of experiments at SLAC discovered quarks in the neutron and proton. Rutherford's experiment is always used in Chemistry I classes, to explain how the nucleus was discovered. It is good then to show how a similar experiment was then used to find out that the nuclear particles were also made up of different particles.

Quarks have mass, spin, electric charge and another form of charge called color. Unlike electric charge, color charge does not exist in the everyday world. All of its manifestations are indirect. It is this charge which binds the different quarks together to form hadrons. It is called color charge because the rules for combining quarks into protons and other hadrons is reminiscent of the rules for combining primary colors to get white light, but it has no real connection to real colors. So when three quarks bind together the resulting hadron has no color charge. Individual quarks do not exist. They always need to be bound strongly by the strong force to form a hadron.

Protons and neutrons are made of up and down quarks. The proton comprises two up quarks with a positive charge 2/3 that of an electron and a down quark with a negative charge of -1/3 of that of an electron, thus giving the proton, the positive equivalent charge to that of the electron. The neutron is made up of two down particles and an up particle, which gives it a neutral charge.

Neutrinos are the elusive particle, which are produced in great quantities at the sun and 40 billion of them of them pass through us every second. In 1930, theorist Wolfgang Pauli introduced the neutrino as a theoretical "remedy" to account for the energy in balance in nuclear equations. He worried that scientists might never be able to detect this seemingly invisible particle. But a quarter of a century later, a Nobel Prize-winning experiment observed the first signs of neutrinos, recording their occasional collisions with matter. Scientists think that the abundance of neutrinos may have played a key role in the shaping of the early universe. For decades scientists assumed the particles to be massless as experimenters found no hint of neutrino mass. In the 1990's new measurements provided the first evidence that neutrinos have mass. Neutrinos appear to oscillate and this is only consistent with having a mass. As neutrinos travel through matter and space they transform from one type to another. Researching neutrinos is extremely difficult due to their lack of interaction with other matter.

After all the particles were found, the most basic seemed to form into three families. The particles that make up matter as we know it, fall into Family I and include the electron, the electron neutrino, the up quark and the down quark. The other two families have a similar structure, with an electron and neutrino counterpart and two quarks.

Family I		Family II		Family III	
Particle	Mass	Particle	Mass	Particle	Mass
Electron	.00054	Muon	.11	Tau	1.9
Electron Neutrino	$<10^{-8}$	Muon Neutrino	<.0003	Tau Neutrino	< .033
Up Quark	.0047	Charm Quark	1.6	Top Quark	189
Down Quark	.0074	Strange Quark	.16	Bottom Quark	5.2

(The masses are in multiples of the proton mass.)

The particles belonging to families II and III have only been found in cosmic material or particle accelerators. Theses particles are not stable and tend to combine and then decay to give particles of the first family. As can be seen from the table, particles in families II and III are much heavier than their counterpart in Family I.

The last set of particles which comprise matter are the particles associated with the four basic forces. The particle associated with the electromagnetic force is the photon. The gluon is the particle for the strong force, the boson for the weak force and the graviton for gravitational force. The weak force has a very short range and is too weak to bind particles into atoms. Rather its most dramatic effect is that it makes all quarks but the lightest ones unstable especially those in family II and III. The weak interaction plays an essential role in the processes that make the sun shine and in building the heavier elements. The strong force holds the quarks together to form the proton and neutron.

Particle Accelerators

In order to probe deeply into such a small entity as an atom or even its constituent particles, you need to concentrate a large amount of energy in a very small region and cause a miniature explosion from which new particles will be created, according to the rules of particle physics. Einstein's equation, $E = mc^2$, is used in reverse, with energy being converted into new particles or unstable heavy nuclei. The units used to measure the masses of the particles are the equivalent amounts of energy needed to produce them.

The large amount of energy is created by accelerating charged particles by moving them through electric and magnetic fields. To create the energy needed the particles need to travel long distances. Magnetic fields are used to create circular paths so that the particles can make many circuits at increasing speeds. Since the particles need to collide, this acceleration must be done to two sets of particles, which are then aimed at each other, once they have been given the desired energy. If the particles hit head on they lose all their energy in a small collision region. A detector is needed to identify the particles produced and measure their energy.   The goal is to produce as many high energy collisions as possible.

Determining what particles are formed cannot be done directly as the particles have very short lives and travel too short a distance to be detected. Instead their existence must be deduced from the behavior of the particles they decay into. Of all the particles, only electrons, muons, photons, neutrinos, and hadrons emerge into the detector.   A detector is made up of several layers, each of which responds differently to at least one of these particles. The particle energy is measured by either of two techniques- either it loses energy inside the detector in which case the energy effectively heats the detector a little and the amount of heat measured or the tracking chamber is built inside a magnet and the particle curves around the lines of the magnetic field as a reflection of its energy.

For the past century, until the 1970s, experiment led theory in basic physics. Since 1970 in particle physics, theory has been ahead with every discovery predicted. At this point there are a number of predictions which need to be confirmed. But for this to occur, a collider which can produce 40 trillion volts is necessary. This is far beyond the capacities of current machines. The Superconducting Super Collider (SSC) was designed with just such capabilities: a 10-ft wide tunnel forming an 83-kilometer- long oval ring, containing two slender beams of a 20-trillion protons traveling in opposite directions. The protons would be kept on their tracks by 3,840 bending magnets (each 17 meters long) and focused by 888 other magnets containing altogether a total of 41,500 tons of iron, 19,400 kilometers of superconducting cable and kept cool by 2 million liters of liquid helium. In 1993 with about half the construction complete in Ellis County, Texas, Congress concerned about the Federal deficit, voted to terminate the project.

History of String Theory

The standard model for matter took care of all the particles which had been detected in accelerators as well as fitting into three similar families and demonstrating a pattern. So why were scientists looking for an even simpler particle of matter. One reason was that they believed that there had to be something simpler than three families with four particles. The other reason that they were not satisfied was that there appeared to be two theories of physics-one for the macro world and one for the atomic or quantum world. There was a common belief that there must be a single mathematical theory that describes the forces that control our universe. General relativity describes the most familiar force: gravity. But quantum mechanics describes the three other forces: the strong nuclear force, electromagnetism and the weak nuclear force. Einstein had spent his last 30 years searching for a way to describe these forces of nature. From the big bang theory we surmise that a tiny nugget of extremely dense matter erupted violently. Over the next 14 billion years the universe expanded and cooled into stars, galaxies and planets. But if we run these events in reverse then the universe gets smaller, denser and hotter as we go back in time. At this point we are in the quantum world. There does not seem to be a discontinuity to account for a change in rules. It is the hope of the string theorists that they have found just such a solution. They propose that they can explain all of nature, from the tiniest bits of matter to the farthest reaches of the cosmos using just one single ingredient: tiny vibrating strands of energy called strings. The theory still has its doubters as we can not see these strings as they are proposed to be only 10^{-35} m in length and cannot be detected by any of our instruments. The theory also evolved somewhat serendipitously although the believers were and are driven by a belief that there is a simpler theory out there and a willingness to let the math rather the lack of a visual picture sustain them.

In the late 1960's a young Italian physicist, named Veneziano, was searching for a set of equations that would explain the strong nuclear force. The story goes that he happened upon a book on the history of mathematics and in it he found a 200-year old equation, first written down by the Swiss mathematician, Leonhard Euler. Veneziano was amazed to discover that Euler's equations described the strong force. He quickly published a paper and was famous ever after.
Euler's equations became the inspiration of several theoreticians. Within this group was a young American physicist, Leonard Susskind. He saw beyond the immediate explanation of the strong force and saw an even deeper implication. He could see that these equations were describing some kind of particle that could vibrate and do things that were not consistent with a point particle. He states that he realized that what was being described was a string, an elastic string, like a rubber band, or like a rubber band cut in half. This rubber band could stretch and contract and even wiggle. Susskind was euphoric as he mailed his insights to a Journal for publication and was devastated when the panel could not see his logic or agree with his conclusions. With little support from the physics community the early pioneers in string theory continued based on belief and fuelled by the elegance of the math and thwarted by several anomalies and the disturbing thought that four dimensions was imposing too many restrictions. Also puzzling was an extra particle which John Swarz of California Institute of Technology proposed was the much sought after graviton.

In the early 1980's string theory was riddled with mathematical anomalies. Michael Green of Cambridge, another believer in the "rightness' of string theory, joined Swarz and they ploughed through the math and were able to reconcile the anomalies. They recognized that the strings could describe gravity but that they also could describe the other forces. So they began to speak of unification and suggest that they had found the "Theory of Everything." The elegant new version of string theory seemed capable of describing all the building blocks of nature. The variations of particles were achieved by different vibrations and tensions within the strings. Even with this new theory there are questions still to be answered. Why is there such a variation in mass between the three families of the standard theory? What is the composition of Dark matter which comprises so much of our universe? What causes the Dark energy?

The theoretical nature of this theory attracts many detractors who feel that because the distances involved are so tiny and the energies so high that it is impossible to make observations to support the theory and more disturbing no observations to disprove the theory. Even for the believers, the math is very daunting.

Objectives

The primary focus of this unit is for students to appreciate the difficult task of theoretical research where supporting evidence is difficult to obtain and the experimenter must have some intuitive moments which come from an understanding of the material and its implication. I would also like students to appreciate the search for a simple explanation and unifying theories. This scientific research involves trying to picture a piece of reality which is like no other reality. Students will be able to trace the development of ideas and see how each new theory builds on prior work. (PPS science standard 1)

Students will be able to describe matter in terms of the standard theory and describe how the particles interact and how they relate to nuclear stability and radioactivity. Also students show an appreciation that the matter that we describe as atoms is the same as much of the matter in the universe. They need to know that atomic 'matter' is only 4% of the matter in the universe and that 73% is dark energy with the remaining 23% dark matter (PPS science standard 2)

Students will be able to describe a particle accelerator and how new particles are found and how the new elements are formed. Students will know where the current facilities are and understand their value. Students will be able to examine the simple paths of particles through an electric field and predict the mass and charge of that particle. (PPS science standard 1 & 2)

Students will be able to give the rationale for the continued research into strings and how data from many different fields are used for theory, tools or analogy. (PPS science standard1)

Students will be able to justify the expense of the new research and give some of its benefits. They should be able to defend this in a written explanation. (PPS communications standard 2)

Students will be able to read scientific explanations from a variety of sources and appreciate the difficult task of explaining highly abstract concepts to the lay audience. (PPS communications standards 2& 3)

Strategies

This unit will have a final activity but will not be a stand alone unit. It is designed to enrich my curriculum in atomic and electronic structure. Much of the material and activities will be integrated into my current course. I will describe where the material will be added and the current and additional activities from this unit.

I start the unit on atomic structure with a historical look at how scientists discovered and developed a theory of the atom. This curriculum unit in many ways just extends this. I start with Democritius' philosophical argument that all matter must a have a final indivisible particle, since indefinite breaking down of matter must lead to a building block of nothing. A big time jump takes us to John Dalton, who looked for an explanation for observations of chemical experimentation. He again introduced the idea of an atom as a building block. His basic ideas are still excellent explanations at an atomic level for what is happening during chemical change. There was no direct evidence of an atom, but his theory made excellent sense of observations at a macro level. The first direct evidence of a sub-particle for the atom was J. Thomson's discovery of light, negative particles seen as a bright light in a cathode tube. At this point I explain to students how scientists determine the charge and mass of a particle by accelerating a charged particle through an electric field. Although students have not had physics they are able to understand the analogy of a snow blower generating a force perpendicular to the path of moving balls of different masses. Students are able to realize that the heavier particle will have its path altered the least. They know enough about charges to understand that a positive charge will be attracted by a negative charge and repelled by a positive charge and that the presence of these charges creates a force similar to the leaf blower. Students are beginning to get a sense of how we can study particles which we cannot see. Movement of a charged particle through either a magnetic or electric field is the concept behind a mass spectrometer.

A standard experiment described in any study of atomic structure is Rutherford's famous alpha particle scattering experiment. It is cited because the results gave the theory to describe the atom as having a positively charged nucleus and electrons, within the scale of the atom, an incredibly far distance from the nucleus. It also seems to be a favorite of teachers because it is an example of an experiment which did not give predicted results, with the unexpected small percentage of the results being critical to generating a new theory. These results required a theory that put aside traditional views and looked at just the data. Rutherford used an alpha particle as a probe to bounce off other smaller particles and then used the path of the particle after collision to provide information about the matter that the original particle hit. This continues to be the basis of particle accelerators where an ever more energetic particle is needed to probe for even smaller particles of matter. An understanding of Rutherford's experiment helps students understand the concept of the particle accelerator.

After I have presented the basic structure of an atom as a nucleus containing a proton and neutron, surrounded by moving electrons and have defined mass number, atomic number and isotopes, I then discuss nuclear reactions. I normally begin by looking at the belt of stability and discussing the importance of the ratio of protons to neutrons. This is where I would present the concept of quarks and the strong force which holds the nucleus together. I discuss the three forms of radiation and then we look at nuclear equations and how the atomic and mass numbers must be balanced. As we examine beta radiation I will discuss the results obtained and how the existence of a neutrino was predicted and how elusive the particle has been to isolate. The concept of anti-matter is introduced when we discuss how atoms rich in protons, transform the proton into a neutron and a positron. After students are familiar with the particles in nuclear reactions and can balance them, binding energy is introduced. Students use $E=mc^2$ to calculate the binding energy and become familiar with the idea that matter is energy and that energy is matter. Once students have calculated several binding energies then we plot binding energy per nucleon versus atomic number and see why iron-56 is so stable and why small atoms will undergo fusion and large atoms will decay into smaller atoms.

The next unit is the arrangement of electrons in the atom and an introduction to quantum mechanics. Students then become familiar with the concept of probability, energy states and spin. After the students can write the electron configuration and understand the periodic chart, I would then describe the standard model. First I would describe how the British physicist, Paul Dirac determined that a positron must exist. He was calculating the energy of an electron and arrived at an expression for E^2, so when he took the square root he obtained two answers for energy. Since according to relativity, energy and mass are interchangeable, this suggested that there was an electron with a negative mass. Students are quite familiar with the rejection of a negative quantity when they solve quadratic equations and so would understand if this negative solution was dismissed. Dirac proposed that the electron had negative energy states possible, but the reason that the electron does not occupy these negative states is because these levels are already occupied by negative-mass electrons. Based on Pauli's exclusion principle there is no room for any positive mass electrons to occupy these states. If an electron was to be excited from this continuum a hole would be created. This hole would have a positive charge (an absence of negative charge) and similarly appear to have a positive mass. This hole behaves like a particle, in fact an electron with a positive charge or a positron. This is a very sophisticated argument and students will not fully understand it but it is an example of a particle predicted by theory and later found experimentally.

After the standard theory has been developed, I discuss the Big Bang Theory and the idea of the unification of the force particles. I also discuss nucleo-synthesis and star formation. See curriculum unit for cosmology, 2004. At this point we will discuss particle accelerators and what has been proven so far and what scientists hope to discover in the near future.

The standard model raises questions and so the historical development of string theory would be introduced. The details of how a string theory in any detail would be over whelming for a tenth grade student. My objectives would be for the students to understand the questions which the standard model raises; understand how incredibly small a string is and the high tension of the string to generate the energies needed; understand that the type of vibration is what will give a string its identity and determine its properties; finally I would like the students to appreciate some of the thinking that lead to the development of such a creative theory. The best source for an easy to understand description is the PBC NOVA program "The Elegant Universe " hosted by the author of the book. This allows the students to grasp the key concepts presented with creative analogies and graphics. The second episode gives an appropriate description of the historical events.

Classroom Activities

Again since much of this unit is integrated into an already established curriculum, I will just highlight those activities related to the new material introduced during this unit.

1. To help students understand the concept behind Rutherford's experiment I will construct an experiment or demonstration. Balls of different masses and speeds will be aimed at each other and students will observe the change in trajectory of the balls after the hits. I use marbles, hard super bouncing balls, soft rubber balls and ping pong balls. Students will observe the effect that the speed of the "probe, size of the probe and its mass have on a target. The target will then be covered and the students will have to guess what comprises the target and what type of "probe" was the most effective.
2. To further understand methods used to gather information about unseen particles. Students will run trials with the Model Mass Spectrometer from Flinn Scientific. Metallic and non-metallic balls are propelled through a magnetic field and the balls collected at the end of their path over a Lucite sheet. Students will better understand the effect of an electromagnetic field on a charged or non-charged particle and a light or heavy mass.
3. Students will read chapter 14 "Holes in Nothing" from "The World of Mr. Tompkins ". This chapter describes how Dirac theorized the existence of antimatter and makes a good analogy using the ocean as the continuum of energies. Students will be asked some basic questions to test for understanding and then asked to assess the effectiveness of the analogy as an explanation. This is a continuation of the cosmology unit (PTI 2004), where students are asked to evaluate many analogies and graphics used to explain some of the difficult concepts around quantum theory, string theory and cosmology.
4. When we discuss the standard model, the neutrino will be introduced. Students will read "Fun with Physics" (New Yorker, June 2, 2003). This article describes how Janet Conrad, a physicist, from Columbia University has designed a method to track neutrinos. With this detector built under an igloo of dirt at the Fermi National Accelerator Laboratory, near Chicago, she hopes to track one of the most elusive yet prolific particles. The article provides an excellent picture of the frustrations of conducting experiments as well as the enthusiasm to continue after setbacks. The road that Dr. Conrad took to become a scientist and her early experiences which excited her curiosity are also described. Students will be asked to describe the nature of neutrinos and the difficulty of detecting them. They will also discuss the interests and enthusiasms of Dr. Conrad. Finally they will be asked to evaluate the article for its ease of comprehension, promotion of understanding of the neutrino and finally its effectiveness in portraying the life of a scientist.

5. The two major particle accelerators, Fermi lab outside of Chicago and CERN in Switzland, have informative and very user friendly websites. Not only do the websites give the physical dimensions and layout of the accelerators but there are many educational links as well describing the concept of a particle accelerator and the results that have been achieved. Students will be assigned one of these particle accelerators and asked to explore the website. Students will then meet in groups and prepare a presentation which will include a description of the accelerator and its size. They will discuss some of the recent discoveries and future construction and projects. The groups will then make presentations to the rest of the class. Students will then compare the two accelerators, for capability, funding and access for scientists.
6. The early chapters of Brian Greene's book, "The Elegant Universe", were produced by NOVA and the program is available on DVD. This is an excellent program with some amazing graphics, analogies and skits. Students will view the program. There are three segments, each a little over 45 minutes long. The lead-in is clever and creative. You will want to watch it the first time but may want to fast forward through it for the last two shows. The first segment starts with Newton's concept of gravity and then describes Einstein's theory of general relativity. The historical development of quantum mechanics is also tracked. Emphasized throughout is Einstein's belief that there should be a unified theory that unites both the theory of relativity which describes the behavior of large and heavy particles and quantum theory which describes the behavior of very small particles.

   After viewing this segment students will be asked to again evaluate the analogies used to describe difficult concepts.

The second segment describes the inconsistencies of the two theories and then gives a historical description of the developments which led to string theory. The dilemmas and the frustrations are conveyed well. Interviews with the actual person who either first proposed a theory, lets students hear first hand their passion for their work.

The class will be asked to read opposing viewpoints about string theory. These are found on the website which supports the program. Joe Lykken discusses why he is an enthusiastic supporter of string theory and continues to research in this area. He also describes the somewhat tedious and difficult tasks associated with this research. Sheldon Glashow, professor of physics at Boston University and winner of the 1979 Nobel Prize, is outspoken about string theory, in particular, the lack of evidence. He decries the lack of interaction between the theorists and the experimenters. He feels that the theory needs hard evidence and a prediction which can be tested. This clash of views between such eminent scientists gives students an insight into the differences that can occur especially when evidence is sparse. After reading these two interviews students will be asked to summarize the beliefs. The next day students will be encouraged to take a side and debate their viewpoint.

The last segment describes some of the more sci-fi implications of string theory- worm holes, parallel universes and multiple dimensions. Again the scientists convey their enthusiasm for the research, their excitement when a breakthrough is reached and their competitiveness to be the first.

After the third segment there will be a class discussion around, the qualities needed to de research in this field, and the frustrations to expect.

7. As a culminating project students will write a letter to the editor supporting or not the continuation of construction of the new particle accelerator in Texas.

Annotated Bibliography / Resources

Barnett, Michael. *The Charm of Strange Quarks*. Springer Verlag, New York, 2000

Gamov, George & Stannard Richard. *The New World of Mr. Tompkins*. Cambridge University Press, UK. Re-printed 2003.
Mr. Tompkins is a bank clerk who attends lectures on Physics and daydreams to give analogies for quantum mechanics, cosmology etc.

Gilmore, Robert. *The Wizard of Quarks*. Copernicus Books, New York, 2001
The wizard of Oz story is used as an analogy for a description of sub-atomic particles. Dorothy visits the Kingdom of Cern and the Wizard of Quarks. Through this fantasy the difficult concepts become easier to understand.

Greene, Brian. *The Elegant Universe*. Vintage Books, New York, 2000
A leading physicist explains string theory and the most basic form of matter.

Gell-Mann, Murray. The Quark and the Jaguar. W.H. Freeman and company, New York, 1994. A description of the standard model and the discovery of the quark

Kane, Gordon. The *Particle Garden: Our Universe As Understood by Particle Physicists.* Addison-Wesley, Reading, Mass., 1995
Describes the sub-atomic particles, how they were discovered and their role. Covers the standard model and string theory. Clear descriptions which are easy to understand.

Weinberg, Stephen. *Dreams of a Final Theory*. Vintage Books. 1992
Describes the grand quest for a final theory which will unify both the quantum world and also explain gravity. A strong argument for building the super collider in Texas is given.

Online Resources

www.fnal.gov the web site for Fermilab offers a wealth of interesting information on the work done there and the scientists who do the work. There is a virtual tour, video clips etc.

www.cern.ch the official web-site for the CERN particle accelerator in Europe. Another rich site with a tour, description of current research and informative background information.

www.particleadventure.org The national Science Foundation and the Department of Energy attempt to answer a collection of very big questions through an illustrated step-through activity that is both fun and informative.

www.superstringtheory.com The award winning site by physicist Patricia Schwarz looks at all aspects of the field, including the history and the major players.

www.pbs.org.elegantuniverse: This web site contains background information to the PBS NOVA show about the book. The shows can be seen on the website. Transcripts of each show are available as are interviews with some of the top researchers in this field. There are some slide shows and animated pieces on background material as well as activities for teachers.

Students

K.C.Cole, *Fun With Physics*, The New Yorker, June 2 2003, page 43
Describes the work of Janet Conrad who is trying to detect neutrinos underground.

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

Science and Technology

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

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

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

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

Reading, Writing, Speaking and Listening

2. All students read and use a variety of methods to make sense of various complex texts.

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

4. All students write for a variety of purposes, including to narrate, inform and persuade.