The Nature of a Scientific Theory

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Overview

"Forty-two!"
According to The Hitchhiker's Guide to the Galaxy, that is the answer to the ultimate question of the Universe. But after 5 million years of calculation, the universe's most powerful computer, Deep Thought, indicates that we don't know what the ultimate question is! Deep Thought then sets about designing a more powerful computer that will take another 5 million years to determine the ultimate question.

Paradoxically the cutting edge of science, theoretical physics, in its search for the Theory of Everything, known as (TOE), may well be facing the same dilemma. String Theory, the predominant TOE currently, which has been pursued for thirty-five years, seems to be in the same situation. According to String Theory the limited "answers" or "parameters" of the theory that we are able to determine are very bizarre. But even more difficult is the fact that we don't even know the question! We haven't been able to even formulate the theory itself. We find ourselves in a very tenuous situation. And it has left many people to ask whether the pursuit of String Theory is even science! This is because String Theory has not posited a testable hypothesis, nor potentially will it be able to for a very long time. So this leads us to the question: What is the nature of science?

In school we are taught that science is based on the scientific method. But it appears that theoretical physics has gotten far from experiment, perhaps inevitably because of limits of technology, perhaps as a result of a lack of cleverness by physicists. Some scientists are looking towards cosmology where technology is providing a source of data. Other theoretical physicists are proposing alternative theories. Many continue to pursue String theory in the belief that its mathematical elegance will pay off in reflecting natural laws. So in light of this dilemma, I would like to consider, 1) What is the nature of a scientific theory? 2) What are the bizarre claims of string theory and are they warranted / 3) What are some of the alternative TOE's and other speculative theories being pursued? 4) What is the current state of cutting edge scientific inquiry? And lastly 5) Does this illuminate the approach that we should pursue as science?

I will be writing this unit for my physics students and to introduce the nature of science to my freshmen general science class to expound on how versatile science actually is when on the cutting edge of knowledge. We must keep in mind that we know almost nothing about 96% of the universe! So although we may know a lot and be able to tell an impressive story about the state of scientific knowledge we must remember how changing knowledge is and that science in particular is exploratory.

Rationale

The Scientific Approach

What does it mean to do science? Clearly it is a rational endeavor to discern the veracity or falseness of truth claims. Lee Smolin, a prominent theoretical theorist who challenges String Theory, differentiates the scientific endeavor as essentially part of a scientific community which is dedicated to discerning truth claims. He suggests that there are two fundamental characteristics that make scientific communities exceptionally able to make progress towards the "truth." These two aspects are that the scientific community is both ethical and imaginative. By an ethical society he means that there is an attempt to be transparent and adhere to a shared ethic. In The Trouble with Physics, he states that "it is adherence to an ethic, not adherence to any particular fact or theory that I believe serves as the fundamental corrective within the scientific community." (p 301) It is the application of rational argument to publicly available evidence and the ability to draw divergent conclusions when there is not consensus. Science "is a way to encourage the discovery of new knowledge, but more than anything else it is a collection of crafts and practices that, over time, have shown to be effective in unmasking error. It is our best tool in the constant struggle to overcome our built-in tendency to fool ourselves and fool others." (p300) It must be remembered that Smolin is a theorist so this certainly affects his sense of what is most significant about science.

The second aspect of a scientific community, according to Smolin, is that it is imaginative. He believes this is the distinction between science and religious societies. It is "a community whose ethic and organization incorporates a belief in the inevitability of progress and an openness to the future… Not only is there a belief that the future will be better, there is an understanding that we cannot forecast how that better future will be reached." (p303) Smolin goes on to expound on the scientific purpose saying that, "Rather than placing faith in their present knowledge, its members invest their hopes and expectations for the future in future generations, by passing along to them the ethical precepts and tools of thinking, individual and collective, that will enable them to overcome and take advantage of circumstances that are beyond the present powers of imagination." (p304) Therefore, science is dedicated to the progress of ideas.

In school we are taught the scientific method. The scientific method is the process by which a hypothesis is formulated. A verifiable experiment is created to test a single variable. The experiment is repeatable. Many experiments are performed to invalidate the hypothesis. Only after the hypothesis has withstood a significant period of not being invalidated by the test is it accepted as a possible scientific theory. After a long time of scrutiny a scientific theory that cannot be disproved becomes a scientific fact or law. This is the scientific method. The goal of the scientist is always to disprove the scientific hypothesis, theory or law. The integrity of this inexhaustible scientific pursuit to invalidate facts is proposed as the heart of the scientific approach.

The theoretical physicist, Lee Smolin indicates that science rarely pursues science via the scientific method. Instead it is a dynamic process that is always different and changing. He makes a distinction between scientific craftspeople and seers. He believes the scientific revolution is dependent on supporting the work of seers who work on the fundamental issues of physics.

Dissent is absolutely necessary for science. “Challenging current belief is the prism, the conceptual lens, through which advances in knowledge are viewed. It does not matter whether the challenges are obvious or obscure, simple or complex, voiced bv few or accepted by many. When challenges are defensible, they act as a scalpel to dissect the latest thinking in the field, teasing apart and exposing critical issues.“ (Smolin, xxvi) Science must challenge the current paradigm.

According to Michael Barnes, “Science is a method for adjudicating truth-claims…science cannot determine values” (Barnes,178) and he indicates that “In science the consensus sought is agreement on what the evidence indicates.” (Barnes, 179) The major elements of the modern scientific method are 1) unitary naturalism, 2) universalism, “Like naturalism, universalism might also be used as only a practical hypothesis. Whoever expects that ultimately all things will fit together into one grand systematic understanding is someone who will go on trying to discover the rational coherence of things. Whoever thus keeps on trying will be more likely to discover whatever intelligibility exists. Like naturalism this has proved to be at least an exceedingly fruitful hypothesis to work with.” (Barnes, 182-3) That all hypotheses, theories, or truth-claims must be tested empirically. 4) That the testing must be public, open to criticism by opponents. 5) That there is no point at which the testing has been completed once and for all, 6) That all scientific truth-claims are therefore tentative, at least in principle “Modern science, by contrast, is highly aware that empirical testing of ideas is extremely important… intellectual beauty is not enough.” (Barnes, 183) This is certainly a challenge that must be leveled against string theory. “To whatever extent there is a failure of “fit,” to that extent there is something wrong that must someday, somehow be resolved if the project of science to understand the natural world is to be carried forward successfully… In light of past successes of an idea, it may be reasonable to hold to it for a time, even in the face of anomalies (i.e. some lack of fit with new evidence). But the lack of fit remains as a warning that something is wrong somewhere” (Barnes, 184-5) The anomaly that string theory attempts to address is the incompatibility of quantum mechanics and gravity. 7) All of science, process and conclusions alike, is a human construction. “Social constructivism interprets science as a product of some particular, and therefore ‘local,’ social interaction or discourse… social constructivists from this is that science does not have any universal validity… Constructivism has been supported by some historians of science, following Thomas Kuhn.” (Barnes, 188) According to Michael Barnes, Kuhn overemphasizes the history of science overlooking evidence in favor of social convention. Barnes says Kuhn suggests, “Social acceptance of the paradigm blocks new tests of its validity because scientists will ignore or explain away any anomalies. But ironically, as Kuhn reviews the historical evidence, he tends to overlook his own evidence that it was evidence, not social approval, which sifted through the various truth-claims and determined the winner… Kuhn’s case should not be that evidence counts for little in science. (Barnes, 195) Barnes indicates that evidence is essential in the pursuit of science. He goes on to indicate that Kuhn “obscures the role of evidence” more in his later work. *The Structure of Scientific Revolutions*. Barnes indicates that “Here he repeats the frequent theme in the earlier book, the role of bias and values. But now he emphasizes much more the factors that sustain "normal science" (i.e. a well-accepted paradigm). Kuhn's account of the response to such "crises" minimizes the impact of evidence…Kuhn's point is partly valid. When anomalies appear in applying a theory that has long functioned well, there are various good reasons why the anomalies should not be taken too seriously… Yet Kuhn also notes that when anomalies continue and accrue, scientists do take this evidence quite seriously. That is why there are "crisis" in science, as Kuhn calls them… Kuhn's own description of the process of science acknowledges the controlling role of evidence in the work of science, even though his commentary on those descriptions points much more strongly to bias and interests and habit than to the role of evidence. This is not the place to attempt a full analysis of Kuhn's theory of scientific developments. It is important only to say enough to argue that any claim that science is merely a "local" enterprise, guided by subjective or social values of a given place and time, does not hold up… The universal validity of modern science for its limited task is difficult to deny… Kuhn claims he is listing certain "values" that guide science. But the values turn out to be five different ways of speaking about how theories and observations can be checked for "fit." (Barnes, 195) In this manner, Barnes effectively challenges Kuhn's analysis that science is value biased rather than driven by evidence. Barnes goes on to highlight the strength of science in its use of checking for best fit among truth claims and reality. "This method of "fit" seems to be the sole effective means we have for checking on the reliability of any of our ideas…Thus science is a set of practices that aid people in applying the everyday mental ability of judging how well things fit or do not fit. The practices of science aid people in doing this with precision and exactness, with full reflective awareness of possible sources of error, and with long-term public criticism. The methods of science are techniques to aid us in that practice, so that our judgments are increasingly exact and reliable. Judging from the results, they are very productive practices… Modern science has accepted the world of appearances and has laid upon it the expectation that it will be an intelligible world, where the events are all part of a natural and "mechanical" (or energist) whole, where the validity of truth-claims can be tested by their fit with all other truth-claims…But after more than twenty-five hundred years of attempts at understanding the world (perhaps minus the half-millennium of the early Middle Ages), of speculation and trial and error, a scientific model of reality has emerged that works so well that philosophical uncertainties do not stand in the way of its effectiveness at its limited task." (Barnes, 198) Through the pursuit of science we have created an increasingly complex and wide-reaching, coherent network of ideas and this is the result of scientists upholding an ideal of objectivity. It is the public and open ended testing that enables us to overcome our human subjectivity. Barnes says that " In spite of the various inescapable subjective factors in every human endeavor, including science, the method of public and open-ended testing means that a variety of people, with different subjective interests, biases, and habits, place demands on each other to take perspectives other than the individual person's original views. By seeking a universally workable set of ideas, science is seeking that which can function as objective truth, truth-claims not dependent on subjective factors except those shared by intelligent human beings anywhere… But the rule that every truth-claim must be submitted to the court of public long-term testing is a rule that enforces a kind of honesty in the end. Science is thus also antiauthoritarian. It is legitimate for any person to doubt any conclusion of science, to dissent from whatever scientific tradition has thus far held strong. This implies a certain degree of individualism as well." (Barnes, 198) So it is clear, according to Barnes that science has been singularly effective in making truth-claims because it is committed to fitting the evidence and that it is open to public testing. It must be asked whether String Theory has failed on both of these counts. Simply speaking, does String Theory have enough evidence to make its claims. Extraordinary explanations require extraordinary evidence and clearly String Theory lacks this evidence. As far as Smolin and others claim, is it possible that String Theory has become so mathematically specialized and insulated that it has at least in part limited the public testing of the theory? Has string theory failed in regard to individualism? Barnes ends his chapter on science saying, "Perhaps we can legitimately call it a faith, or at least a hope or expectation, that reality is intelligible. But it is by no means a blind faith or an unjustified faith… This success confirms the practical efficacy of the scientific method. Science contains a further faith in the human capacity to discover more and more of the intelligibility of reality through the exercise of reason and empirical investigation, following the basic rules about public and long-term testing… The ongoing enterprise of science is perhaps an implicit act of trust that human achievements in science have fundamental meaning or value." (Barnes, 199) Science relies on the belief that the universe is intelligible. So is String Theory an extraordinary attempt at furthering our comprehension of the universe or a misguided pursuit that has diverged so far from evidence and the scientific method as we understand it that it can no longer be considered science? In order to consider this question, we must first understand a lot more about what String Theory actually claims. We will look at how Leonard Susskind, a major contributor and proponent of String Theory explains its development.

Science has changed and evolved and modern science has introduced some factors of uncertainty and statistics that are difficult to incorporate into our world view. Robert Kuhn explains this shift away from determinism indicating that "Quantum mechanics is different from classical theory. In classical theory, if you knew all the data, you could toss a coin and predict the outcome with certainty. But now we know that's not so. There is a fundamental quantum nature that in some sense frees us from this determinism." (Robert Kuhn, 342) Science has changed its process in its pursuit of knowledge. The question I will pose about String Theory is whether in embracing highly speculative ideas and pursuing a mathematical aesthetic if it has not left the boundaries of science behind.

Susskind explains the scientific pursuit and String Theory in particular, indicating that "Physicists, particularly theoretical physicists, have a very strong sense of beauty, elegance, and uniqueness. They have always believed that the laws of nature are the unique inevitable consequence of some elegant mathematical principle…
The universe has more in common with a Rube Goldberg machine than with a unique consequence of mathematical symmetry… Much of what we know comes from experimental cosmology and modern astronomy. Two key discoveries are driving the paradigm shift – the success of inflationary cosmology and the existence of a small cosmological constant." (The Cosmic Landscape, p.12-13) So we must now consider the claims of String Theory, the evidence behind it, the logical fit to reality in an attempt to eventually discern whether it is in fact a scientific pursuit that is expanding the scientific

endeavor or whether it has exceeded the limits of science and has gone into the realm of faith.

String Theory

So the question at hand is whether or not String Theory is a scientific theory. It has not made an independent prediction that cannot be explained by other methods and it is currently untestable and has been, by any known technological means, for 35 years. And it is possible, although, it is the dominant theory in physics that it may not be testable for a very long time. In fact, the theory itself has not been formulated and it is not singular. It is postulated that there may be as many as 10^{500} different versions, known as the Landscape by Leonard Susskind. The theory requires at least 10 dimensions and likely at least 11 to be mathematically consistent and to incorporate the 5 known supersymmetric versions of the theory. So is this belief in the elegance of the mathematics of String Theory in fact a scientific pursuit?

Well, it doesn't lead to an easy answer. From an external point of view, in the absence of any evidence, in light of the need for 7 extra dimensions and the proliferation of variations of the theory, which hasn't even been formulated, it must be considered that this pursuit may not be science. Certainly it is not science as we have known it in the past and if it proves to be wrong it may well be seen more in light of a fanatical pursuit driven by emotion and a desire for elegant mathematical unification, however, as Leonard Susskind indicates, it is far from elegant!.

However, if it proves to be a true unification, then String Theory is a visionary pursuit of scientific and mathematical truth. Is it possible that the pursuit of science can be defined by an outcome that we don't know? So when will the string wars be resolved? Possibly in 2008 when CERN is operational, evidence may be found one way or the other. Otherwise, it could be a very long time before the debate is resolved.

Let's consider what Leonard Susskind, a leading String theorist, has to say about String Theory. In his book, Susskind indicates that his understanding of String Theory embraces the anthropic principle. He says, "Until very recently, the Anthropic Principle was considered by almost all physicists to be unscientific, religious, and generally a goofy misguided idea… But a stunning reversal of fortune has put string theorists in an embarrassing position: their own cherished theory is pushing them right into the waiting arms of the enemy. String Theory is turning out to be the enemy's strongest weapon. Instead of producing a single unique elegant construct, it gives rise to a colossal landscape of Rube Goldberg machines. The Cosmic Landscape is my answer, as well as the answer of a growing number of physicists and cosmologists, to the paradox of a benevolent universe." (Susskind, 14-15) Given the inconceivable number of possible universes of String Theory, String theorists are forced to explain how life and the laws of our universe exist and frankly they are not up to the task.

Inflationary cosmology, which itself is only tangentially supported, forces String theorists to some bizarre consequences. Susskind indicates that "Inflationary cosmology, which is our best theory of the universe, is leading us, sometimes unwillingly, to a concept of a megaverse, filled with a prodigious number of what Alan Guth calls "pocket universes" … We live in one tiny pocket where the value of the constant is consistent with our kind of life. That's it! There is no other answer to the question." (Susskind, 21)

According to Susskind, "There are four principal developments driving this sea change: two from theoretical physics and two from observational astronomy. On the theoretical side an outgrowth of inflationary theory called Eternal Inflation is demanding that the world be a megaverse… At the same time, String Theory is producing a Landscape of enormous diversity. The best estimates are that 10^{500} distinct kinds of environments are possible… The newest astronomical data about the size and shape of the universe provide confirmation that the universe exponentially "inflated' to a stupendous size much bigger than the standard ten or fifteen billion light-years. There is very little doubt that we are embedded in a vastly bigger megaverse. But the biggest news is that in our pocket of space, the notorious cosmological constant…is not quite zero as it was thought to be. The discovery has rocked the boat more than any other… The fact that it is not absent is a cataclysm for physicists, and the only way that we know how to make any sense of it is through the reviled and despised Anthropic Principle." (Susskind, p21-22) This does not strike me as a particularly scientific argument. Instead it seems like a very speculative and desperate attempt to explain implications of facts that are not understood. Is this science? And Susskind doesn't even address here the difficult supposition that the mathematical formulation of String Theory demands that there are at least ten dimensions. This is explained by the supposition that the six extra dimensions must be curled up very small, into Kaluza-Klein spaces on the Planck length. This would prevent us from noticing them because they would only be accessible at extreme energies. Ed Witten indicates that at least eleven dimensions are required to unify the five known supersymmetric String Theories into M-theory. This introduces the idea of "branes" which are 2-D membranes within the 10 dimensions. Apparently, to Susskind, this is not even problematic enough , as a premise, to indicate it as one of the main challenges of String Theory.

For the prediction of the cosmological constant based on mathematics, "The problem is that the wrong result seems to be an inevitable consequence of our best theory of nature, quantum field theory…the best efforts of the best physicists, using our best theories predict Einstein's cosmological constant incorrectly by 120 orders of magnitude! That's so bad it's funny." (Susskind, 66) Susskind addresses the cosmological constant as Einstein initially suggested it, saying, "Many things are wrong with this theory. From the theoretical point of view, the universe that Einstein had built was unstable. It was in equilibrium but *unstable equilibrium*…Einstein's static universe was like the unstable upside-down pendulum. The slightest perturbation would either cause it to explosively grow or implode it like a popped balloon…The cosmological constant is equivalent to another term that may be easier to picture: the *vacuum energy*… The vacuum is empty space. By definition it is empty, so how can it have any energy? The answer lies in the weirdness brought to the world by quantum mechanics, the weird uncertainty, the weird granularity, and the weird incessant jitteriness… These short-lived quantum particles that fill the vacuum are called *virtual particles,* but their effects can be quite real. In particular, they cause the vacuum to have energy. The vacuum is not the state of zero energy. It is merely a state of *minimum energy*." (Susskind, 71-73) Susskind explains the vacuum energy now associated with Dark Energy. He goes on to say more about the vacuum energy. "But if energy and mass are the same thing, then this sentence could also be read: 'Energy is the source of the gravitational field.' In other words, all forms of energy affect the gravitational field and, therefore, also influence the motion of nearby masses. The vacuum energy of quantum field theory is no exception. Even empty space will have a gravitational field if the energy density of the vacuum is not zero. Objects will move through empty space as if there were a force on them. The interesting thing is that if the vacuum energy is a positive number, then its effect is a universal repulsion, a kind of antigravity that would tend to drive galaxies apart. This is exactly what we said of the cosmological constant earlier… If there really is a cosmological constant, or vacuum energy, then there are severe limits on its magnitude. If it were too big, it would lead to detectable distortions of the trajectories of astronomical bodies. The cosmological constant, if not zero, must be very small indeed. The problem is that once we identify the cosmological constant with vacuum energy, nobody has any idea why it should be zero or even small. Evidently, combining the theory of elementary particles with Einstein's theory of gravity is a very risky thing to do. It seems to lead to an unpromising universe with a cosmological constant many orders of magnitude too big." (Suskind, 74) Susskind goes on to discuss the conundrum that String Theroy faces and attempts to resolove, indicating that "If we add up all the energy in this sea of particles using the technical mathematics of quantum field theory, we find a disaster. There are so many high-energy virtual particles that the total energy comes out infinite. Infinity is a senseless answer… The estimate that quantum field theory gives is so big that it requires a 1 with 116 zeros after it: 10 to the 116th power… It is far more energy than all the stars in the observable universe will ever radiate in their entire lives. The gravitational repulsion due to that much vacuum energy would be disastrous. It would tear apart not only galaxies but also atoms, nuclei, and even the protons and neutrons that make up the galactic material." (Susskind, 74)

Thus the dilemma that science faces is how do we account for the existence of a small cosmological constant? Its existence is fundamentally problematic. "For a bunch of numbers, none of them particularly small, to cancel one another to such precision would be a numerical coincidence so incredibly absurd that there must be some other answer. Theoretical physicists and observational cosmologists have regarded this problem differently. The traditional cosmologists have generally kept an open mind about the possibility that there may be a tiny cosmological constant. In the spirit of experimental scientists, they have regarded it as a parameter to be measured. The physicists, myself included, looked at the absurdity of the required coincidence and said to themselves (and each other) that there must be some deep hidden mathematical reason why the cosmological constant must be *exactly zero*. This seemed more likely than a numerical cancellation of 119 decimal places for no good reason. We have sought after such an explanation for almost half a century with no luck. String theorists are a special breed of theoretical physicist with very strong opinions about this problem. The theory that they work on has often produced unexpected mathematical miracles, perfect cancellations for deep and mysterious reasons. Their view (and it was, until not too long ago, also my view) has been that String Theory is such a special theory that it must be the one true theory of nature. And being true, it must have some profound mathematical reason for the supposed fact that the vacuum energy is exactly zero. Finding the reason has been regarded as the biggest, most important, and most difficult problem of modern physics. No other phenomenon has puzzled physicists for as long as this one. Every attempt, be it in quantum field theory or in String Theory, has failed. It truly is the mother of all physics problems." (Susskind, 78) This argument leads Susskind to support the anthropic principle. Does this exposition on the search sound scientific or is this speculation verging more on religion? Susskind indicates that "theorists' discomfort with the idea [of the anthropic principle] had to do with their hopes for a unique consistent system of physical laws in which every constant of nature, including the cosmological constant, was predictable from some elegant mathematical principle." (Susskind, 84) Susskind is suggesting that scientists must recognize and accept that the universe is not entirely intelligible and that the Anthropic Principle is the only choice. This is a break in the scientific endeavor as it has been pursued throughout its history as indicated by Barnes. The question we must ask, is it warranted?

So Susskind suggests the Landscape as the solution. He indicates that "the Landscape is a space of possibilities… The Landscape has hundreds, maybe thousands, of dimensions… It doesn't exist in space and time at all. It's a mathematical construct, each of whose points represents a possible environment or, as a physicist would say, a possible vacuum… The Laws of Physics are determined by the environment." (Susskind, 90-3) So there are nearly an infinity of possibilities, so we must rely on the existence of intelligent life as a defining parameter in choosing which options are viable. "Most significant changes in the Laws of Physics would be fatal and therein lies a tale that we will return to repeatedly… At the present time our best bet for these higher-level laws – our only bet- is String Theory… we will see that String Theory has an unexpected answer to the question of how many fields control the local vacuum weather. From the current state of knowledge, it seems that it is in the hundreds or even thousands." (Susskind, 96-7) So String Theory, which hoped to simplify the free parameters of the Standard Model, has failed and resulted in a magnification of the problem.

So how does Susskind justify the existence of the inconceivably improbably Cosmological Constant? He suggests that there are so many possible vacuums in String Theory that it makes the possibility of 10 to the 120^{th} look like a highly probably event… he suggests that there are 10 to the 500 possible vacuums! Does this seem like reasonable, rational science? Susskind suggests that approximately 14 billion years ago we were on a sloping plateau of the Landscape and descended into a valley of our current vacuum in the event known as the Big Bang.. Susskind amazingly reasons that "That one of the minima should have vacuum energy as small as 10^{-120} is incredibly improbable. But… the real Landscape of String Theory is far more complex, diverse, and interesting. Try to imagine a space of five hundred dimensions with a topography that includes 10^{500} local minima, each with its own Laws of Physics and constants of nature… But one thing seems certain. With that many possibilities to choose from, it is overwhelmingly likely that the energy of many vacuums will cancel to the accuracy required by Weinberg's anthropic argument, namely 119 decimal places." (Susskind, 109) I can't help but wonder if this is scientifically rigorous reasoning or a desperate attempt to find any solution.

So Susskind suggests that we must look at science entirely differently. He challenges the nature of the scientific pursuit and may even suggest that it is not entirely scientific, as Thomas Kuhn would probably agree, saying, "The anthropic controversy is about more than scientific facts and philosophical principles. It is about what constitutes good taste in science. And like all arguments about taste, it involves people's esthetic sensibilities. The resistance to anthropic explanations of natural facts derives, in part, from the special esthetic criteria that have influenced all great theoretical physicists… A proof of a theorem should be as lean as possible; meaning that the number of assumptions, as well as the number of steps, should be kept to the minimum… uniqueness is another property that is especially highly valued by theoretical physicists… The best theory would be not only a theory of everything, but it would be the only possible theory of everything. The combination of elegance, uniqueness, and the power to answer all answerable questions is what makes a theory beautiful." (Susskind, 111-4) But Susskind argues that the theory of uniqueness and elegance is a myth. "String Theory makes sense only as a theory of 'quantum gravity'… String Theory is not only a physical theory about nature. It is also a very sophisticated mathematical structure that has provided a great deal of inspiration for pure mathematicians…We know neither what the fundamental equations of the theory are nor even if it has any. Well then, what is the theory, if not a collection of defining equations? We really don't know." (Susskind, 123-4) This sounds a lot like the conundrum in The Hitchhiker's Guide to the Galaxy and the ultimate question. And Susskind goes on, "Although no one can identify the defining equations, the methodology of the theory is very rigorous. It could have failed any of a large number of mathematical consistency tests…As we learned more about the theory, three unfortunate things began to happen…stupendous Landscape opened up… The theory also exhibited a nasty tendency to produce Rube Goldberg machines. In searching the Landscape for the "Standard Model, the constructions became unpleasantly complicated... Finally, adding insult to injury, the potential candidates for a vacuum like the one we live in all have a nonzero cosmological constant… String Theory has gone from being Beauty to being the Beast." (Susskind, 125) And yet, remarkably, and not very scientifically, based on faith, Susskind says, "And yet the more I think about this unfortunate history, the more reason I think there is to believe that String Theory is the answer." (Susskind, 125) Remarkable is it not? Is this pure faith?

Susskind admits that "String Theory has no lack of enemies who will tell you that it is a monstrous perversion." (Susskind, 126) But for Susskind he explains his belief saying "But even the cosmological constant would not have been enough to tip the balance for me. For me the tipping point came with the discovery of the huge Landscape that String Theory appears to be forcing on us." (Susskind, 185) So Susskind speculations on a Landscape lead him to accept the anthropic principle and thereby to believe in String Theory. Susskind says based on a paper and its support that the Landscape was so huge that it could "overcome" the unlikelihood of tuning 120 digits, "That was it for me. I concluded that the only rational explanation for the fine-tunings of nature would have to involve both String Theory and some form of anthropic reasoning." (Susskind, 200) Is this rational thinking?

String theory is incredibly ambitious, as Greg Benford indicates, "String theory is certainly the most complex physical theory ever advanced. And you can tell, because all these brilliant people are having a visibly difficult time with it- which is encouraging, since a really great theory that tells us everything ought to be really hard; it shouldn't come to one person in a weekend, It's the best clue that we may be on the track of something large. But what we're on the track of is still very mysterious. The idea that particles are not little dots but strings that vibrate sits at the core. Of course, that's another chimpanzee metaphor. But the implications are huge: It goes from Andrei's [Linde] cosmology to the fundamental way you glue all these particles together." (Kuhn,

345) Is it rational to suggest that difficulty is a valid indication of a theories potential validity?

There is a need for a TOE to advance the Standard Model. Leon Lederman says, “The Standard Model is a powerful theory that explains all the data coming out of all the accelerators since Galileo dropped those two “students” [weights, actually]- one fat, one thin- off the Leaning Tower of Pisa. But one of the problems with the Standard Model, as we’ve touched on, is that gravity has not been incorporated into it gracefully. And the Standard Model itself is ugly. Six quarks, three colors each; six leptons [the electron, the muon, the tauon, and their neutrinos]; the bosons, or force carriers, like the photon and the gluons. The Greeks promised us aesthetic simplicity, a beauty and an elegance that we don’t have. We can’t even fit all these particles on a T-shirt.” (Kuhn, 345) But in fact, doesn’t Susskind’s description of String Theory indicate that it is even uglier?

Concerning the need for a TOE and quantum mechanics Robert Kuhn says, “The great mystery of quantum physics is that it works. Really weird stuff at the subatomic level forms rather ordinary stuff at the human level, so that the uncertainties and probabilities of the quantum world produce the certainties and absolutes of our normal world. The experimental data is now overwhelming in its scope and captivating in its elegance. Quantum physics is simply the way everything had to be, explaining the behavior of the small zoo of subatomic particles that make up the atoms of the hundred or so elements that in turn make up an unlimited multiplicity of molecules. But the Standard Model remains incomplete: Gravity must be integrated with the strong nuclear and electroweak forces to yield a Theory of Everything, the A Holy Grail of physics. The best current idea drops down a level lower and envisions seemingly mystical, minuscule strings, all wrapped up in ten dimensions, whose vibrations may make the universe sing. It gives a chill to reach so deeply into reality. But quantum physics has made people queasy from it inception. If you’re unconvinced of its truth, don’t feel bad-you’re in good company. Albert Einstein never accepted it either. Which just demonstrates how very difficult it is, sometimes, to get closer to truth.” (Kuhn, 350) So the question posed, is this valid science pursuing truth claims by time tested methods or a radical and desperate enterprise of faith attempting to explain the scientific crisis faced by the anomaly of gravity and quantum mechanics that faces us. It is my conclusion that the answer resides in the validity of the mathematics that are involved. This certainly seems like a pursuit based on faith, but without exception the String Theorists indicate that the mathematics are enticing to such a degree that these bizarre explanations seem reasonable. I suspect that we will have to allow time to determine the ultimate fate of String Theory. Is it valid science or false faith?

According to David Gross, a Nobel Prize winner, three compelling reasons for believing in String Theory are that it explains the unification of forces at very high energies. This is known as the hierarchy problem, and it is solved by supersymmetry. The second support is that the Standard Model with superpartners allows for unification. And lastly, Supersymmetry, according to Gross, is the perfect proposal for the dark matter particle.

Inflationary Theory

There are alternative explanations that exist that attempt to incorporate gravity and quantum theory and to propose TOE's. This will include a discussion of quantum gravity and loop theory.

Before I go into these topics, however, I would like to explore the speculative nature of inflationary theory. Inflationary theory certainly seems to set the tone for the speculative nature of String theory. About inflationary theory, Andrei Linde indicates "when you ask this question you are assuming that the world is everywhere the same. But in fact our new theory of inflationary cosmology tells you that your universe must be incomprehensibly huge, and it may be divided into many, many regions, all of which may be absolutely different from one another. So there are some regions where the world is absolutely bizarre and you cannot live there, and there are some regions where everything is ordinary and you can live there. That's why you can have science." (Kuhn, 348) Linde goes on to explain the beginning of the universe by indicating, "When and how did the universe begin? The best current theory is the Big Bang. The cosmology story now embraces the idea of inflation as well to solve some of the problems that it faces. "Observational data over four decades have remarkably and consistently supported the Big Bang and laid the Steady State to rest. One of the more powerful corroborations of the Big Bang was the discovery in 1965 of the cosmic microwave background radiation, a lingering remnant of the primordial explosion, which permeates the universe at the predicted temperature of about three degrees above absolute zero. However, recent research now suggests that the Big Bang, awesomely, may have been far bigger than that: The Big Bang may have been followed immediately by a period of short-lived but exponential inflation-a theory that seems to solve a number of cosmological puzzles. There have been various versions of inflationary theory; one of them known as chaotic inflation proposes that the universe resembles a huge, rapidly multiplying fractal-an irregular, self-similar pattern (like clouds or coastlines) in which each part appears as a reduced-sized copy of the whole. This mega-universe would consist of many separate universes (in only one of which we live), each undergoing episodes of initial inflation and producing new universes randomly, ad infinitum. Its evolution has no end-and may well have had no beginning. But how can we draw such fine-grained portraits of the universal origin? What methods can reach back over many billions of years? And how many billions? The proposed cosmic life span has been variously pegged at ten, twelve, fifteen, or twenty billion years, and cosmologists are closing in on the number. Why should we care? Because beyond just knowing- which is important enough- what happened so very long ago may carry very great meaning for human understanding today.' (Kuhn, 351-2) In fact, we know now from supernovae data that the Universe is in fact expanding.

Inflation is further explained by Andrei Linde by indicating that, "Inflationary theory describes the very early stages of the universe, and it enormous, though short-lived, expansion. The standard Big Bang a theory held that the universe began as a very, very big explosion- an expanding fireball. But then we found that this big explosion was not big enough to explain everything we see in the universe. At the end of the 1970's it was proposed that the early universe came through a stage of inflation, an exponentially rapid expansion in a kind of unstable heavy vacuum-like state (a state with large energy density but without elementary particles). A vacuum-like state in inflationary theory is usually associated with a scalar field, which is often called the inflation field." So instead of imagining the beginning of the universe as very hot, we imagine it at the beginning as this kind of an unstable vacuum-like state that did not contain any elementary particles but which did contain this scalar field. It is totally empty, without any particles, but still has a lot of energy. And I will be in trouble if I try to explain it in any more detail without using jargon of quantum field theory and general relativity… the potential energy of the scalar field. And then, a fraction of a second after the Big Bang, a region of this scalar field starts expanding exponentially. This is our universe, and at this stage it expands much faster than in standard Big Bang theory, and eventually-after another fraction of a second- the scalar field decays. And after that, the evolution of the universe and the formation of elementary particles can be described by standard Big Bang theory." (Kuhn, 355-6) Although inflation is becoming a widely accepted theory, the conception of eternal inflation poses even greater challenges to rational thinking.

In indicating the potential diverse universes created by inflation, Andrei Linde explains how the concept of eternal inflation has become more acceptable, stating that "Initially, inflation was considered as an intermediate stage of the evolution of the universe, which was necessary to solve many of these cosmological problems. At the end of inflation, as I said earlier, when the scalar field decayed, the universe became hot, and its subsequent evolution could be described by the standard Big Bang theory. Thus inflation was a part of the Big Bang theory. Gradually, however, the Big Bang theory became a part of inflation cosmology. Recent versions of inflationary theory assert that instead of being a single, expanding ball of fire, the universe looks like a huge, rapidly multiplying fractal. This fractal-like universe consists of many inflating balls that produce new balls, which in turn produce more new balls, ad infinitum. Therefore the evolution of the universe, as you mentioned in your introduction, has no end and may have had no beginning… After inflation, the universe becomes divided into different exponentially large domains, inside of which properties of elementary particles and even the number of dimensions of space-time may be different. Thus, the new cosmological theory leads to a considerable modification of the standard point of view on the structure and evolution of the universe and on our own place in the world. (Kuhn 359) In order to explain the scale of the universe and the possibility that we only can see a very small part of the universe, Linde discusses exponential inflation and how it resolves the three primary problems in cosmology. He describes how the theory of inflation has altered the current view of cosmology, stating that "The total size of the observable universe-the part of the universe we see right now- can be described by the number 10^{28} centimeters…a pretty huge number on the human scale. Well, the question is, Why is the universe so large? We needed a theory to explain these great dimensions. There was also another question: Why don't parallel lines intersect? At first, this seems kind of stupid- everyone knows that parallel lines do not intersect. But Einstein told us that the universe is curved, and in a curved universe parallel lines eventually may intersect. So why has no one ever seen parallel lines intersect? And there are many other questions like that, such as why different parts of the universe started to expand simultaneously, and why we see the homogeneity you referred to- that is, everywhere we look in the universe, it looks very much alike. These were the problems, and we got the answers… Inflationary theory, however, does give us a simple answer to all of these questions simultaneously. When you get the answer, you cannot forget it… The answer is that the universe expanded extremely fast in this vacuum state. The main difference between inflationary theory and the old cosmology becomes clear when you estimate what the size of the universe should be after the expansion. You get, not 10 to the power of 28, which is the current size of the observable universe, but 10 to the power of one trillion-or even greater than that, depending on the model." (Kuhn,360) Linde explains that the homogeneity, the Flatness and the Horizon problem are all solved by inflation. The question still remains for me whether this is a reasonable theory and whether the resultant implications of eternal inflation are a necessary consequence?

Inflation describes a brief period of expansion that is exponential and difficult to imagine. "The scales and orders of magnitude in inflationary theory are astonishing and they are critical to appreciate its ultimate significance. During the universe's fleetingly brief inflationary era (perhaps only 10^{-35} to 10^{-32} seconds), it is said to have increased in size by a factor of at least thirty orders of magnitude (10^{30}) and perhaps far more. According to some inflation models reported by Linde, the universe could have expanded to 10 to the trillionth power. It is impossible to conceive of a physical representation of this number." (Kuhn, 360) This expansion of space's faster than the speed of light, and is allowable, even according to the limits of relativity by Linde, who states that "Einstein's relativity applies to light. It does not apply to the speed of expansion of the whole thing- all space-time. There is no upper bound on the speed of inflationary expansion in the early universe, even though light still travels at the same speed. Inflation theory tells how fast the whole of space expanded." (Kuhn, 361) Space is capable of expanding faster than the speed of light.

Penrose challenges the basis of the initial conception of inflation, although he doesn't exactly deny the existence of inflation. A contrary explanation to inflation is offered by Frank Tippler. "Andre [Linde] mentioned this scalar field, this vacuum field, but he neglected to mention that you have to invent it ab initio. It exists only in the theorists' minds. I prefer to use fields that people like Leon [Lederman] have already seen. So if you just use standard physics- that is, relativity and quantum mechanics and the Standard Model of particle physics, which involves fields we've actually observed, then there's a unique solution to how the universe began. And it began in a singularity [a point of infinite density], out of which sprang gravitation and all the other laws, energy, and matter of the universe. Now, there is an energy field- what we call a gauge field, which we're all familiar with as theoretical physicists. That's the only field we have in our normal experience. One way for you to think about it is as something like light. It's not quite light but something resembling it… a unique solution" (Kuhn, 361-2) However, I have reservations about Tippler because he is a proponent of the strong Anthropic principle.

This does highlight the bizarre and potentially speculative nature of inflationary theory. String theory is another step along that path of speculation and potentially diverges from the scientific pursuit and falls more into philosophy or mathematics.

Alternative Theories

Some of the other concepts that I have come across that are worth addressing in relation to String Theory are the limit of the speed of light and the implication that at the speed of light, the time dimension disappears. I am curious about the implications that this has for the nature of time and whether or not it is an independent entity, an amalgam of space and time dimensions or an illusion in the background independent geometry of space-time. I am also curious to explore the concepts of limits brought up by Planck. The Planck length in relationship to relativity seems to indicate that there is a limit to the dilation of the special dimension in the direction of motion. If an "object' with Planck length is moving close to the speed of light, is it true that there is a limit imposed by the spatial dilation that results in an infinity of time? Thus there would be two limits on the space-time geometry that result in a limit of c, which indicates a stoppage of time and the Planck length which may indicate an infinity of time. These thoughts are just beginning to be formulated and it would be interesting to inform the students of their potential implications. However, they do challenge our very fundamental conception of time. Perhaps time is an illusion. Maybe as David Gross indicated in his lecture "The Future of Physics," time is an emergent phenomenon.

An additional theory involves the consequence of the Planck energy limit. At least to some (referenced by Smolin) this seems to indicate that in the early universe photons with extremely high energies might have been able to exceed the speed c, thus indicating the possibility of casual contact of the CMB. The idea is that high energy photons may actually exceed the limit of the speed of light. This would, at least in part, preclude the need for inflationary theory. Although, discredited by Richard Holman, this theory indicates that there are physicists seriously pursuing alternative theories to inflation to explain the 3 primary problems faced by cosmology.

These theories, which contradict the accepted tenets of physics, are intriguing and I believe may be fruitful to explore. It may be interesting to compare these "outlandish" theoretical consequences with the claims of string theory. I'm not sure that there is enough room to do justice to these theories but it may be interesting to the students to be aware of the variety of theories currently espoused.

"Goodbye, and thanks for all the fish." (Hitchhiker's Guide to the Galaxy)

Objectives

Science has been attempting to produce a theory of everything (TOE) for almost a century. We will discuss the nature of this pursuit and the limitations that it imposes. Creating a comprehension of and enthusiasm for the current understanding of modern physics and the possibility of having a Theory of Everything must be tempered by the evidence that enables scientists to make truth claims. What is a scientific theory and does String Theory satisfy this? This unit is intended to instill enthusiasm in students about the current and relevant issues of science and cosmology. Students require a base of understanding to be able to understand the current advances in scientific knowledge and to build a framework to grasp the new improvements of technology. Many of the modern issues in physics are never addressed in high school. Making the pursuit of a theory of everything pertinent to students will be accomplished by having the students construct a vision of the universe as it currently exists. This new paradigm will motivate students to modify their view of the universe and potentially to define the nature of a scientific theory. The knowledge that the Big Bang results in a singularity that challenges both relativity and quantum mechanics will encourage students to embrace new theories about the construction of time and space. Then we will discuss the primary components of a scientific theory and whether modern theoretical physics requires that we modify our conception of the scientific pursuit.

The students will expound on their current conception of what is the scientific pursuit of knowledge as they understand it and evaluate the course that String Theory has taken over the past 35 years to determine whether their conception of science should be adapted or if in fact String Theory does not meet the criteria for a scientific theory. The students will formulate concepts about the formation of our universe and will face the challenge that our current understanding of physics is unable to answer what occurred in the early formation of the universe. Their imagination will be sparked by the revelation that if the cosmological constants were altered even slightly that life would not be possible. It is a human endeavor to understand the nature of our reality, and String Theory is an attempt to unify our disparate comprehension of the universe. So on a fundamental level the study of cosmology requires the reinvention of our place in the cosmos. Throughout history humans have struggled to come to terms with the nature of reality and now the vastness of cosmology forces us to embrace the sheer magnitude of a universe that is billions of light years across and that was formed in the potential singularity that was the Big Bang. However, physicists are undaunted by this vastness and instead strive to comprehend the nature of the universe and its beginning. The judgment about our place in the cosmos is theoretical by the nature of the question but science attempts to illuminate some of the parameters of that discussion. The attempt to deal with the early universe has demonstrated the limitations of our current understanding of fundamental physics. Students must evaluate the magnitude of knowledge presented by string theory and cosmology and consider how science pursues a comprehensive theory of everything. Concurrently, though, it is also essential to keep in mind that String Theory and cosmology are still in their infancy and advances are made every day. Therefore the scientific search for truth is unfolding and dynamic. The truths that we find are temporal and the search is ongoing so students come face to face with the malleability of our knowledge and the requisite desire to comprehend. However, it is our responsibility as worldly citizens to consider what is a reasonable scope for the pursuit of science. Cosmology demonstrates the need to assess information, to formulate conclusions and to constantly reanalyze the conclusions. Scientists do not know if String Theory is true and it will be a long time before it is even testable, however, the pursuit of a comprehensive understanding of the nature of reality, free of anomalies is an invaluable lesson for all students. Science is constantly advancing towards fuller understanding and the theories that we have are only our best guess about the nature of reality as we currently grasp it. However, String Theory, and the anomalies in relativity and quantum mechanics, make it abundantly clear that our understanding is very limited. We don't even know the full equations of String Theory, but the mathematical elegance of String Theory has given many scientists the conviction that this theory is worth investigating. So whether or not String Theory is correct, the study of String Theory and its development is potentially an invaluable study of the scientific process. If it is deemed to be an unscientific method of pursuing truth claims, then this should inform the students future decisions about what constitutes the scientific approach.

Students will be able to explain how scientific principles of chemical, physical, and biological phenomenon have developed and relate them to real-world situations. (S1) Students will understand how the universe developed into galaxies and stars and how stars fused matter together to form all the matter in the universe. Eventually matter resulted in life on earth. Students will demonstrate knowledge of basic concepts and principles of physical, chemical, biological and earth sciences (S2). The students will construct and evaluate scientific and technological systems using models to explain or predict results (S5). The various models of the Big Bang and the resulting creation of the universe, including expansion, will be investigated. The anthropomorphic ideas that have often led man to place himself at the center of the universe will be addressed and all students evaluate advantages, disadvantages and ethical implications associated with the impact of science and technology on current and future life (S7). The students will utilize the immense resources on the internet and demonstrate basic computer literacy, including word processing, software applications, and the ability to access the global information infrastructure, using current technology (S9). In addition to the scientific emphasis, the string theory unit will address the mathematical methods and tools used in the study of relativity, quantum mechanics and cosmology. All students use numbers, number systems, and equivalent forms (including numbers, words, objects and graphics) to represent theoretical and practical situations (M1). Math is the language of physics and must be utilized to comprehend the current advances being made. All students compute, measure, and estimate to solve theoretical and practical problems, using appropriate tools, including modern technology such as calculators and computers (M2). Explaining the status of our current scientific understanding all students will formulate and solve problems and communicate the mathematical processes used and the reasons for using them (M3). All students understand and apply basic concepts of algebra, geometry, probability and statistics to solve theoretical and practical problems (M5). Much of relativity, quantum mechanics and cosmology is based on the mathematical application of statistics to interpret the information that is gathered from a vast array of sources. Math enables this data to be correlated into meaningful sources of knowledge. All students evaluate, infer, and draw appropriate conclusions from charts, tables and graphs, showing the relationships between data and real-world situation (M6).

Strategies

This unit will be based on a constructivist approach. First I will endeavor to find out what the students know about what comprises a scientific theory. Multiple educational strategies will be instituted to achieve the learning objectives. The evidence that leads to the pursuit of a unified theory and String Theory will be provided in presentations that focus on historical information and the state of our current knowledge. Interspersed with the information will be opportunities to graphically represent the information. Students will have many opportunities to diagram the information presented. The theoretical and speculative nature of scientific exploration lends itself to discussions regarding the nature of our evidence, the uncertainty of the information and its potential implications. Discussing how science proceeds in its pursuit of knowledge even when its theory is currently untestable allows for active rational exploration by students because science is experiencing constant revision and creation. It is invaluable for students to experience the scientific method in action. Simply explaining the advances in this science over the past decade and the respectability string theory and cosmology have achieved in the last twenty years, powerfully illustrates the dynamic quality of the study of science. However, a large part of this unit is going to be about exploring the nature of the scientific pursuit. What comprises a scientific endeavor? When is an exploration beyond the limits of science and reliant on faith? A large part of this unit is going to be a discussion of the nature of the scientific approach including the students understanding of the scientific approach. It is my inclination, that most students will explain the pursuit of science as the scientific approach. How will they feel about theoretical physics of the likes of String Theory that so radically departs from this approach. How will the students feel about the pursuit of science with so little data to rely upon.

In addition, the immense resources of the internet will be incorporated by having the students explore current websites and prepare presentations on the current issues. This will undoubtedly impress the students with the pervasiveness of scientific endeavor. Video resources will also be utilized in the classroom to bring the leaders in string theory and cosmology into the classroom in thoughtful and enervating presentations that can not be reproduced otherwise. All of these methods will be used to hook students into the enthralling advances cosmology is currently experiencing. This will enable us to then discuss the current state of science, as it exists, including String Theory, and come to some conclusions about how science should proceed. Of course by the time we introduce this unit, the LHC at CERN will be operational and data may begin to be presented in support or contradiction of String Theory.

Classroom Activities

THE NATURE OF SCIENTIFIC THEORY (3 class periods)

Discuss the Nature of a scientific theory. What is the scientific method? How have we used the scientific method in middle school and high school science? Is it an effective method of pursuing truth claims?

Write a one page paper on the benefits of using the scientific method to determine truth claims. What science have the students participated in that have led them to be able to prove their scientific claims? What labs have the students performed that have expanded their knowledge since grade school? What are their most memorable science experiences?

Debate: The scientific pursuit of knowledge is the most effective way of pursuing knowledge. Affirmative and Negative based on the students conceptions of the scientific method.

Our scientific knowledge is changing rapidly! Cosmology is a great example of the nature of science. We present our best theories and keep correcting them. We attempt to make our theories as comprehensive as possible.

INTRODUCE RELATIVITY AND QUANTUM MECHANICS AND DISCUSS HOW STRING THEORY ATTEMPTS TO BE A TOE AND RESOLVE THE

INCOMPATIBILITY OF THE TWO PILLARS OF MODERN PHYSICS (1 class period)

Discuss Einstein's General Theory of Relativity. Introduce the concepts of curvature of space and fluctuation of time. Discuss space-time and the limit of the speed of light. Explain that relativity requires smooth continuous space. Demonstrate the affects of motion on time by diagramming a light clock in motion. Illustrate the concept of the relativity of simultaneity with the moving train. Discuss the particles of quantum mechanics and their relationships. Use the CPEP chart "Standard Model of Fundamental Particles and Interactions" to indicate the relationships. Stress the incredible accuracy and predicting power of quantum mechanics. Discuss quantum mechanics lack of explanation for why reality exists as it does. Indicate the bizarre implications of statistical quantum mechanics and occurrences such as quantum tunneling.

Discuss the fact that singularities result when both relativity and quantum mechanics are required simultaneously. These situations occur at the extreme conditions of the early universe and in the extreme gravity of black holes. Singularities result in the nonsensical solution of mathematical formulas and indicate the limits of the two pillars of modern physics. A more comprehensive understanding is required to make these two theories compatible.

The study of the universe from the large scale to the small has led to the development of string theory and the possibility of achieving the "theory of everything (TOE)." Explain what is meant by vibrating strings and how these vibrations of energy results in all of the known particles. Introduce the concept of extra dimensions and explain that the incredibly complex mathematics of string theory requires at least six extra space dimensions and most likely seven for the unification of M-Theory. Illustrate extra dimensions by referring to "flatland" and how a two dimensional being would experience three dimensions. Discuss the implications of string theory on quantum mechanics and relativity and how it is possible that String Theory could unify the four interactions.

Supplemental Video- <u>The Elegant Universe</u>

<u>The Elegant Universe</u> discusses the development and implications of superstring theory and quantum mechanics. This video comprehensively explains the development of string theory and illustrates the essential concepts of multiple dimensions and the bizarre consequences of quantum mechanics.

PRESENT THE CURRENT STATE OF COSMOLOGY (1 class period)

The History of Cosmology –

Historically cosmology had little respectability and was largely perceived as a "quack" science. In the beginning, astronomers could merely plot the position of stars. The limited power of telescopes and technology severely limited astronomers' ability to determine the basic characteristics of the universe. Initially it was believed that the earth was at the center of the universe. In time, using the motions of the stars and planets it was realized that the sun was at the center of our solar system and it was realized that there were many solar systems in our galaxy. It was long believed, though, that our galaxy encompassed the entire universe. Gradually it was discovered that our galaxy was only a small portion of the celestial bodies. With the development of technological tools and a more systematic approach, scientists like Hubble brought respectability to cosmology. Hubble established the fact that certain light sources were not merely stars but were actually entire galaxies that were very far away. By analyzing the light from these galaxies he discovered that the light from these galaxies was what is called "red shifted." This means that the frequency of the light from these galaxies was shifted in frequency to the longer end of the light spectrum and appeared more red. This is known as the Doppler shift. This remarkable discovery led Hubble to the proper interpretation that these galaxies must be moving away from us. By calculating the amount of the red shift, Hubble was able to significantly validate the study of cosmology as an empirical science. Continued measurements have demonstrated that Hubble was correct in postulating that all the galaxies in the universe (with only a few local exceptions) are in fact accelerating away from us. This was established because galaxies that were further away were more red shifted than those that were closer. Hubble could have postulated that we were consequently at the center of the universe, but given the history of the failure of the anthropomorphic viewpoint it was hypothesized that the entire universe was expanding away from everything else because space itself was expanding. Today many of the brightest physicists and mathematicians are involved in the study of cosmology. The theoretical implication of the study of cosmology on the scale from the very large to the very small has placed cosmology on the cutting edge of scientific exploration.

Group Discussion-
Introductory Set- How old do you think the universe is, did it have a beginning, how big is the universe and what do you think the fate of the universe will be? This discussion will address the scientific, cultural and religious preconceptions of the students.

The History of our Universe- The Big Bang Theory
Once Hubble discovered that the universe was accelerating outward the existing theory that the universe was static was debunked. The universe was in a state of flux so what the universe was different in the past. Since all matter and space was expanding outward there must have been a time when the matter was contracted. This led to the theory of the Big Bang. Extrapolating backward in time, all matter had a trajectory back to the beginning of time and that trajectory led to the proposition that the universe began in a fantastic explosion. All of the math indicates that a singularity would have occurred at that time so our equations can not take us all the way back to the beginning but they do indicate back within the initial moments of our current universe. All matter was condensed into an infinitesimally small space at millions of degrees. A rapid expansion occurred that propelled all matter out from a single point. We are still experiencing the consequence of that initial expansion. Science cannot say whether time existed before that time but it is possible that if this expansion was eventually overcome by gravity that the universe could collapse back on itself and the process could be repeated.

Discuss "The History and Fate of the Universe" CPEP Chart
Discuss Horizon and Flatness Problems

The Horizon Problem deals with the question of how the universe is so isotropic (2.7 degrees Kelvin CMB within 1 part in 10^5) when there was not enough time in the early universe for photons to communicate.
The Flatness Problem addresses the unlikelihood of Ω being so nearly 1 (almost exactly the critical mass value within 9 decimal places).

Introduce Inflation –
Inflation is the event in the very early universe, 10^{-35} seconds, when space itself expanded exponentially. This is an example of how science with mathematics is able to address problems nearly beyond the imagination

The Fate of Our Universe-
Once it was determined that the universe was moving outward the next question regarded the state of the universe: Is the universe going to collapse back into itself or will it escape the gravitational pull of the mass of the universe and continue expanding outward forever? Initial calculations were not conclusive as to the future of the universe but gradually it was determined that the universe did, in fact, have terminal velocity and will continue expanding outwardly forever. The gravitational contraction of the universe was not enough to stop the expansion so the universe will continue outward. It was assumed that the universe would decelerate from the gravitational affect but it has been determined recently that the universe is actually accelerating! The cause of acceleration is unknown but may be as a result of the cosmological expansion constant. Within the last billion years the universal expansion constant has become dominant and has resulted in the transition from deceleration to acceleration. Supernova and CMB Data have independently determined that the universe is accelerating! This has required the postulation of dark energy and dark matter to explain the universe as we perceive it. Based on this data, baryonic matter only makes up 4% of the universe. Incredibly, the majority of the universe we know almost nothing about!

Supplemental Video- Runaway Universe
Runaway Universe discusses the implications of the calculations that the universe is actually expanding and explains how this conclusion is derived. Einstein was the first to propose the cosmological constant which is a repulsive force also known as antigravity, but he introduced it in his equation because he believed the universe should be static. Now it has been established using standard candles that the universe is accelerating. Dark Matter holds our galaxy together and dark energy is responsible for the expansion of the universe.

DEBATE WHETHER OR NOT STRING THEORY IS A SCIENTIFIC THEORY? (1 class period)
Does String Theory meet the student's expectation of what it means to be a scientific theory? Does String Theory present enough evidence to back up their claims? Is it possible for a scientific theory to be primarily theoretical or mathematical? Is it problematic that String Theory has not been able to produce a testable claim?

Annotated Bibliography/Resources

Annotated Bibliography

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Understanding Uncertainty. NOVA. 1998.

Lecture

Gross, David. "The Future of Physics- What We Don't Know." The Carnegie Mellon Buhl Lecture, 2007.

Appendix-Content Standards

Appendix: The following standards will be incorporated into the String Theory unit.

SCIENCE STANDARDS
S1. All students explain how scientific principles of chemical, physical, and biological phenomenon have developed and relate them to real-world situations.
S2. All students demonstrate knowledge of basic concepts and principles of physical, chemical, biological and earth sciences.

S5. All students construct and evaluate scientific and technological systems using models to explain or predict results.
S7. All students evaluate advantages, disadvantages and ethical implications associated with the impact of science and technology on current and future life.
S9. All students demonstrate basic computer literacy, including word processing, software applications, and the ability to access the global information infrastructure, using current technology.

MATH STANDARDS
M1. All students use numbers, number systems, and equivalent forms (including numbers, words, objects and graphics) to represent theoretical and practical situations.
M2. All students compute, measure, and estimate to solve theoretical and practical problems, using appropriate tools, including modern technology such as calculators and computers.
M4. All students formulate and solve problems and communicate the mathematical processes used and the reasons for using them.
M5. All students understand and apply basic concepts of algebra, geometry, probability and statistics to solve theoretical and practical problems.
M6. All students evaluate, infer, and draw appropriate conclusions from charts, tables and graphs, showing the relationships between data and real-world situation.