The Elegant Universe

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Overview:

The use of the scientific method has been instrumental to the development of sciences across the curriculum. Scientists based their theories on what they observed, then created theories to make sense of those observations in their heads. When mathematics could be used to prove or disprove their theories scientists could then modify or expound upon their theories as necessary. This process has proven itself invaluable time and again. Not only did scientists use the scientific method to create the founding theories of Biology, Chemistry, and Physics but this was also the same method we use today to solve both scientific and everyday problems.

The chemistry text used today asks students to compare Dalton's, Thompson's, Bohr's, and Schrödinger's models of atoms using various laws and principles, but really gives no backlog of how science has evolved to incorporate these theories or where scientists are headed with new theories being developed. Teachers are to adhere to a set curriculum making sure that students are exposed to and understand a certain set of standards, while at the same time expecting our students to become "experts" without an understanding of how the science evolved or the big picture. How can students understand a solution to a problem if they were never exposed to the question, just the answer? If students are going to understand atomic theory and how things in the universe work they need to understand matter on an atomic level, and better yet a subatomic level. In order to fully understand this, students need to be exposed to the processes scientists have developed and refined over time. Once our students can understand where the science came from, it then becomes our job as teachers to strike them with awe. We need to introduce our students to the most recent discoveries and theories being developed, hoping that interest will pique. Without exposure to discovery students will only see theory, and not understand why scientists keep trying to find more and more fundamental levels of matter. Science is the future, and so are our students, it is our job to get them to find which direction they want to take it.

One key component that needs to be understood is that scientists will never be happy with what they know. There will always be another question to ask. We do not really run into problems until we reach a quantum or subquantum level, but the problems still arise. We are limited today by our ability to measure. Here is where this unit starts to directly tie into the high school curriculum. Students want to participate in hands on activities but do not understand the importance of being both accurate and precise with their measurements. Just like the physicists today studying the string theory, the results of any experiment are only as good as the data collected. Compared to the particle accelerators used to collect data for the cutting edge scientists of today, the tools we use in high school are quite primitive. The point however is to emphasize the process not the tool. The key to being successful in science is persistence and ingenuity. We have all heard the adage practice makes perfect, well that is part of the hopes of the high school curriculum, or at least to learn familiarity. We try to instill the scientific method into our students from grade school on. We are moving towards using an inquiry based approach to science in order to train students to ask questions. When we prove or disprove one question we then have to reanalyze and figure out what the next logical question to ask is. This innate questioning has been the basis for the development of the sciences over time. The question now becomes how we get our students to make that jump in understanding from what we can see, to what we can figure out. Many people can understand the necessity or need for atoms and the parts of atoms, but when we start discussing particles that make up the parts of protons, neutrons, and electrons we lose more and more people. The process of conceptualizing these tiny particles makes us rely on the math and theory together. Connecting the two becomes more and more difficult as we delve into particles that are smaller and smaller. This unit discusses how the view of the fundamental particles has changed over time.

Obviously there are plenty of problems to be solved, but the main focus is to find a way to get our students interested in research, and to want to be the one to answer that next question. To identify a timeline of how sciences, chemistry in particular, have evolved is one way to instill this to our students. In order for students to see how important research and experimentation is, they need to fully understand where we started from, but not end there. We need to expose students to a more complete time-line, one that starts with science from the beginning and reaching into the future. We need to make them part of the time-line, get them to make some type of connection to the exponential growth of knowledge.

The question now becomes how can we instill the process of asking the question how does this work, or how does this make sense. The most promising rejection is well I can’t see it, so why should I care. In order to get around the most obvious rejection is to prove that it makes sense, through theory and mathematics. What would make even more of an impression is to get them into a lab to actually see what experiments are being done, and get them exposed to the process of developing science as a career option.

Rationale:

This unit is meant to be supplemented into a high school chemistry course in order to stress the importance of the scientific method and to encourage its continual use throughout a students' life not only during science class but in order to solve everyday problems. The unit may be helpful for students in grades 10 – 12 in a regular education or inclusion classroom. Students will benefit from becoming acquainted with the process of creating a theory, then testing the theory, revising, testing again, and then re-revising. It must be stressed that just like in the writing process the steps of revision are not limited. Knowledge and understanding need to be continually reassessed, supplemented, and revised.

The current expectations for high school students according to the Addison-Wesley Chemistry text are to know what alchemy was and to know the four parts to Dalton's atomic theory. There is a slight mention of Democritus and the "atomist" school of thought, but no discussion of how the theory came about. From Democritus we flow right into the discovery of the subatomic particles: protons, neutrons, and electrons. In order to show the magnitude of the particles we use an analogy of the head of a straight pin on the 50 yard line of a football stadium being the nucleus of an atom and the rest of the stadium being the electron cloud of an atom, then we leave the structure of an atom. There is no mention of quarks or other fundamental particles making up the protons, neutrons, and electrons unless further supplemented by the instructor. Further into the text we come back to the development of atomic theories, but it is only enough to expose students to the names of the theories. There are drawings of the Thompson model, Rutherford model, Bohr model, and the Quantum mechanical model. It seems as though these theories are only mentioned so that students know there seems to be rules about where electrons can be found, which have evolved through experimentation. Atomic emission spectra are introduced to explain what happens when electrons become excited, and then we leave off with the mention of the Heisenberg uncertainty principal.

There is no mention of where atoms came from, how they were created, what it means to be made of atoms or anything of the sort. It is imperative that students understand that there is more to the universe than just Earth and the humans on it. The basic understanding of what the universe is and how it became is lacking to say the least. Students at Oliver High School are not exposed to information about the universe, how it was created, or what is happening within the universe now. This unit is meant to at least provide minimal information to students regarding various topics: what the universe is, what the big bang was, why we believe the theories behind the big bang are correct, and some of the processes followed to create the theories and describe some of the changes to the theory over time. This unit will cover parts of theories from the origin of the universe – the big bang, up to and including the string theory and how what is believed about fundamental particles of matter have evolved.

The Scientific Revolution

The development of cosmology and the sciences is ancient. For my purposes I think that a review of Ptolemy should begin our journey of understanding how chemistry can be used to study where the universe came from and where it is heading. Ptolemy suggested that the Earth was the center of the universe based on his observations. This is important because at the high school level this is really what one of the objectives of doing labs is, to prove theories based on observation. In order to make sense of what Ptolemy's theory entails, we must first pause the unit to ensure students have an understanding of what the universe is. Do not assume that students understand that there are more than 9 planets, or that there galaxies other than the one we are part of, nothing should be assumed, and you must first form a working definition of what the universe is. Once there is a common understanding of the universe it will make more sense to discuss why Ptolemy would think that the Earth was at the center. The introduction of the Big Bang theory will then allow a logical following of why scientists would question how the Earth could be at the center of the universe when what was being observed disproved the theory, leading to the modification of the theory.

The Big Bang theory will introduce the idea of an expanding universe. It is important to get students to understand that points in the universe are moving away from each other, but that does not mean that we are expanding. Activity 3 can be done as a demonstration or as a lab where students will see how we are decoupled from the expansion of the universe. It is difficult to understand how when we look around we do not see the expansion, but if you are thinking at a universal level, that it will take longer to get from point A to point B because of the expansion. Another analogy which is commonly used to show how two points can move further from each other is to place two points on a balloon. As the balloon is inflated, the points separate on the surface. This analogy has limits though, if you use stickers as your points they may fall off, and if you use a marker, your spots will expand, which is exactly what you are trying to prove does not happen.

Before scientists realized how vast the universe really was, they had to come up with a theory relating our planet to the rest of the universe. Ptolemy was an ancient Greek philosopher who predicted the positions of the planets pretty accurately based on his observations. Ptolemy's predictions placed the Earth at the center of the universe, he was fairly accurate, but that was not good enough. Copernicus was the scientist who suggested that the Earth was not at the center of the universe, but that it was actually the sun, we call this a heliocentric universe. This point was particularly hard to swallow for many just because as humans we want to believe that we are special, and that we belonged at the center of the universe. The reason Copernicus was able to argue for his theory was that mathematically he could explain the appearance of retrograde motion of the planets as they circumvent the sun. Like Ptolemy's theory however, Copernicus also had to "fudge" his numbers because he believed that the planets had to travel in circles.

Kepler was the scientist who chose to disregard the requirement that the planets had to move in a circular orbit, he knew that there had to be a reason the data did not quite fit the model, so he chose to analyze other possible explanations. Kepler only chose to discard the circular orbit idea after he had exhausted every possibility of making the concentric circles theory work. He then tried the next-simplest shape, an ellipse. When using elliptical orbits he found that the data for Mars matched up perfectly with the theory. This shows how scientists figured out what our solar system and galaxy looked like as they kept developing better tools to enable them to see further. We also need to look at the question of how the universe came into being. This question asks us to more or less rewind history to figure out what made up the universe.

The theory most astronomers, physicists, and chemists believe explains how the universe came about is the Big Bang theory. The big bang theory says that everything started with a giant explosion everywhere at the same time, as in there is no center of the universe. Originally the Big Bang theory suggested that the universe was expanding, we still believe this today, but the data again just did not fit the model. In order to explain the difference, scientists suggest that there was an inflationary period. This means that most of the universe we know of today became in the first 3 minutes after the big bang. The Contemporary Physics Education Project published a timeline for the Universe breaking down the history into 4 different eras. Era 1 only applied to the first 10^{-43} seconds or a Planck time. Era 2 includes up to the first 10^{-12} seconds which is when nucleons form. Inflation of the universe is said to have commenced between the first 2 eras. The third era goes up until 4×10^{5} years; during this era is when atoms form. Stars and Galaxies form around 3×10^{8} years, and today we are around 14×10^{9} years which is considered era 4.

Now that we have an understanding of how the idea of the universe has changed over time we need to come back to the development of Chemistry as a science and its usefulness in cosmology. Steven Shapin in the Scientific Revolution wrote that it was parts of Aristotle's theories of traditional natural philosophy which guided the beginnings of Galileo's work. (Shapin, 18) Galileo should be part of our curriculum because he was willing to look at the data he collected to come up with his theories. This is another key part of the scientific method. If scientists did not collect and then analyze their data, there would be no validity in their findings.

Copernicus used his skills of observation to develop cosmology and challenge the theories which had been accepted before him. Copernicus played a major role in developing cosmology based on data, which then evolved into other sciences. According to Shapin, "much of Galileo's astronomical and physical research in the early seventeenth century was undertaken to lend credibility to a new physical model of the cosmos that had first been published in 1543 by the Polish prelate Nicolaus Copernicus." (Shapin, 20) I think these are all important aspects to expose our students to. They need to understand that one scientist alone did not create a theory and then it was published and scientists worldwide believed it. We need to instill the idea of trial and error, of revision, and of working collaboratively. These are skills that are not only needed in the scientific community but in everyday life as well.

Even during the sixteenth century scientists thought that eventually our knowledge would outgrow what could be observed. Shapin wrote,

> "Newly observed entities that posed uncomfortable problems for existing philosophical systems were seized on by those eager to discomfit orthodox theorist. Who could confidently say what did and did not exist in the world when tomorrow might reveal as yet undreamed of inhabitants in the domains of the very distant and the very small." (19-20)

Scientists understood that their theories were only laying a framework for what was to come. This seems to be a tradition now, but we need to make sure that our students are willing to put in the grunt work to keep this tradition going. According to A. F. Chalmers in <u>What is this thing called Science?</u> we tend to focus too much on the relationship between theories and observation. By trying to focus on specific observations we fail to understand the complexity of overarching theories. (Chalmers 104) It is as though we need to have the theory first, and then match the observation. In order to understand where science is headed, we need to be able to explain to our students what theories are being developed, such as the string theory so that they can decide if those theories are theories they would like to pursue personally. Some instances allow scientists to come up with the theory or align the theory to the data after the collection; in some instances this fits string theory. Brian Green, in the Elegant Universe came up with the following analogy:

> "String theory has the potential to be the most predictive theory that physicists have ever studied – a theory that has the capacity to explain the most fundamental of nature's properties – physicists have not as yet been able to make predictions with the precision necessary to confront experimental data. Like a child who receives his or her dream gift for Christmas but can't quite get it to work because a few pages of the instructions are missing, today's physicists are in possession of what may well be the Holy Grail of modern science, but they can't unleash its full predictive power until they succeed in writing the full instruction manual." (211)

This quest for understanding is what has driven scientists for centuries, and hopefully for centuries to come. We now need to show how this continued quest for knowledge has developed over time. In J. R. Paddington's A Short History of Chemistry we see that the Greek philosophers were the first to have the idea of an element, starting with Thales (640 – 546 B.C.). Empedocles (490 – 430 B.C.) changed the existing theory to involve the four "roots" of things: fire, air, water, and earth. He also included two forces which were attraction and repulsion. This first scientist to actually mention "elements" was Plato (427 – 347 B.C.). According to Plato each of these four roots had their own specified shape. Around 400 B.C. was also the period when Alchemy was considered a scientific career. This was when scientists tried to turn everything into gold. The reason Alchemy is significant is that scientists used trial and error. They took a substance heated it, added other substances and recorded how it had changed. The Alchemists may not have been successful turning substances into gold, but they were successful in studying chemical reactions.

It was Aristotle who summarized the theories that came before him, and decided to call what made up everything *húle*. Aristotle understood that matter changed from within, and he called the change *eidos*. So over 2,400 years ago there was a beginning of trying to understand chemical changes and how these changes occurred. In order to fully understand what the universe is made of we must figure out what matter is made of, and try to go backwards in time piecing the data together. This means that we need to truly understand the atomic theory, and figure out what is the most fundamental part of matter.

In general Paddington believes that chemistry had its origin around the beginning of the Christian era. Democritus, another Greek philosopher, is known as one of the founders of the atomic theory. Democritus's atomic theory said that everything was made of tiny indivisible particles called atoms, but there was no experimental evidence to back up his theory. Over time the atomic theory has been changed several times. John Dalton revised the original atomic theory to include that elements of the same atom are identical, and that atoms can be rearranged in simple whole number ratios, but not created nor destroyed. This is important because in order to make these changes Dalton analyzed his observations from experiments, where he was actually trying to figure out the ratios in which different elements combined in chemical reactions.

The cathode ray tube and J.J. Thompson's experiments using it led to yet another change in the atomic theory. Thompson knew that atoms were neutral, but during an experiment flowing electricity through gases he proved that atoms were not indivisible as Dalton had suggested, but that there were negative changes inside of atoms, which are now referred to as electrons. Robert Millikan took it upon himself to experiment with the notion of an electron further, his results gave accurate values of both the charge and the ratio of the charge to mass of an electron.

Since atoms were known to be neutral it seemed only natural that upon further investigations the counterpart to an electron would be discovered. Sir James Chadwick uncovered the existence of the neutron, which is not the counterpart to an electron, but is indeed another subatomic particle. Ernest Rutherford was the scientist who did discover the existence of the proton through experimentation. His gold foil experiment showed that when radiating a beam of alpha particles at a piece of gold foil that not all of the alpha particles would shoot through the foil and line up at the back of the receiving screen as expected. Some particles were reflected back towards the alpha source or deflected at an angle onto the screen. Since alpha particles are positively charged it was deduced that there had to be positive particles inside of an atom which would cause the unexpected deflection. Since very few particles were detected in unexpected areas Rutherford theorized that most of the mass of an atom is found in a tiny central region of the atom, now known as the nucleus. Since most of the mass is found in this tiny nucleus of the atom, Rutherford also theorized that most of the rest of the atom is empty space.

Another important revision to Dalton's atomic theory was the discovery of isotopes. We no longer believe that atoms of the same element have identical masses. Henri Becquerel, Pierre Curie, and Marie Curie all received Nobel prizes for their work aiding in the discovery of spontaneous radioactivity and radioactive isotopes. Science is always about asking the right question, one question was why do radioactive elements have isotopes and nonradioactive elements do not? Francis Aston received the Nobel prize in 1922 in chemistry for his discovery of isotopes in non-radioactive elements. Chemistry really took some giant leaps in development and refinement in the past few centuries, it only seemed natural that scientists would start to really think about what the real fundamental part of matter is.

Physicists today are working on putting together a theory of everything. We would be unable to come up with a theory of everything if it hadn't first been for the expertise provided by the theories presented by Bohr, Thompson, and other founding chemists. Many chemists have focused on trying to determine what the most fundamental particle is, so that we can truly understand where we came from, and how everything works. From the discovery of atoms scientists continued to question if that really was the most fundamental particle, until they discovered protons, neutrons, and electrons. Delving further into the atom scientists were able to develop quantum mechanics with their knowledge of Quarks, Leptons, Mesons, and Gluons. From quantum mechanics scientists continued to question what the most fundamental part really is. The predominant theory today is the string theory. There are 5 versions of the string theory: type I, types IIA and IIB, and the two heterotic string theories. If scientists can come up with a theory of everything we will be able to understand the origin of the universe, and try to figure out how we got to where we are today. It is like we are trying to understand the universe in reverse. This theory will relate all sciences across the curriculum, reinforcing the importance of being well rounded and knowledgeable in various areas.

Objectives:

Pittsburgh Public Schools Standards

CO2 All students read and use a variety of methods to make sense of various kinds of complex texts

CO4 All students write for a variety of purposes, including to narrate, inform, and persuade in all subject areas

CO6 All students exchange information orally, including understanding and giving spoken instructions, asking and answering questions appropriately, and promoting effective group communications

MA1 All students use numbers, number systems, and equivalent forms to represent theoretical and practical situations

MA2 All students compute, measure, and estimate to solve theoretical and practical problems, using appropriate tools including modern technology such a calculators and computers

MA3 All student apply the concepts of patterns, functions, and relations to solve theoretical and practical problems

MA5 All students understand and apply basic concepts of algebra, geometry, probability and statistics to solve theoretical and practical problems

MA6 All students evaluate, infer, and draw appropriate conclusions from charts, tables, and graphs showing the relationships between data and real-world situations

CI5 All students develop and defend a position on current issues confronting the United States and other nations conducting research analyzing alternatives, organizing evidence and arguments, and making oral presentations

CI8 All students demonstrate that they can work effectively with others

ST1 All students explain how scientific principles of chemical, physical and biological phenomena have developed and relate them to real-world situations

ST2 All students demonstrate knowledge of basic concepts and principles of physical, chemical, biological, and earth sciences

ST4 All students explain the relationships among science, technology, and society

ST5 All students construct and evaluate scientific and technological systems using models to explain or predict results

ST6 All students develop and apply skills of observation, data collection, analysis, pattern recognition, prediction and scientific reasoning, designing and conducting experiments, and solving technological problems.

ST7 All students evaluate advantages, disadvantages, and ethical implications associated with the impact of science and technology on current and future life

ST9 All students demonstrate basic computer literacy, including word processing, software applications, and the ability to access the global infrastructure, using current technology

CW3 All students understand and demonstrate the importance of relating their academic and vocational skills for example interviewing, critical thinking, decision making, problem solving, understanding, and giving written and oral instructions – to their ability to seek, obtain, maintain, and change jobs

Strategies:

The students at Oliver High School will use this unit as a supplement to the current curriculum. The students will attend science class seven periods per week. Two of these classes will be doing hands on activities in the chemistry laboratory. The way students are tracked at Oliver High School allows them to take Technology and Environmental Science, Biology, Chemistry, and Physics without ever being exposed to universal theories during their high school careers. It will be beneficial to students who have not been exposed to topics such as what the universe is since their middle school science classes.

There are some schools now that administer the PSSA Science exam, and the test will become mandatory in 2008 for all students. Students who have not learned about the universe recently will be at a disadvantage when it comes time to take the test. Some schools utilize an Earth and Space Science curriculum as their junior high science course, or as their 9th grade science course which includes the Big Bang theory and the universe. At Oliver High School Earth and Space Science is usually only a course taken by individuals who have not met the prerequisites for Chemistry and Physics and there is not much information about the universe as a whole covered.

This unit is meant as a supplement to the core Chemistry curriculum to try to tie together the concepts of space science, chemistry, and physics. In order for students to have a full understanding of where we came from they need to know what the big bang was, and why scientists believe that is was the big bang which led to the development of the universe, our solar system, galaxy, and ourselves. We often focus on the details of what we think is important within our curriculum but forget to step back and take a look at the big picture. This unit allows us to do both, focus on the details of the theories regarding the universe, how they are changing, and how they relate to other sciences. This also allows us to tie in how changing theories continue to change with new discoveries. By introducing the string theory in this unit we allow students to understand that scientists are always trying to understand nature and how things work. The string theory is a quest to understand how the universe was created by looking at the most fundamental parts of matter. Here we tie in theory, mathematics, and experimentation together, to come up with the theory of everything; I do not think there could be any topic which could be more overlapping between curricula.

Classroom Activities:

Activity #1 The Universe Adventure

This activity is an interactive CD called the Universe Adventure. It is a Field Test Version done by the Particle Data Group. The CD allows students to learn about the universe both broadly and specifically gradually testing students' knowledge along the way. There is also a directed reading packet to go along with the cd.

http://universeadventure.org/

Appendix A

Activity #2 Determining the Geometry of Space

On a "small" scale the curvature of our universe is negligible, however on the cosmological scale the curvature of the universe has a greater effect. This activity explores the three shapes our universe could possibly have: open, closed, or flat. Just as the escape velocity of a planet is determined by its mass and radius, the universe escape velocity depends upon its mass and size. Since the universe has been found to be expanding at an accelerating rate, there is a need to explore the possible shapes of the universe. This activity explores the distribution of galaxies over a wide range of distances.

See Appendix B

Activity #3 The Expanding Universe

This activity uses motorized vehicles traveling in an expanding universe to show how objects within the universe are moving further away from each other even though they are traveling in the same direction. It shows that even though the universe is expanding the vehicles themselves are not expanding.

Procedure:

1. Get two long springs laying them 8 ½ inches apart. Tie pieces of paper to the parallel springs so that once the vehicles are in motion the "universe" can expand lengthwise. Here the "universe" is the area between the springs, one participant will be showing the expansion of the universe by pulling the springs backward.
2. Get two battery operated motorized vehicles, from a local dollar store, which will act as two points in the universe.

3. Have two volunteers place the vehicles, turned on, on the universe at the same time. As the vehicles are placed on the universe, roughly 3 feet apart, a third individual will start to pull on the springs to expand the universe. The paper that has been tied to both springs will hold back the second vehicle making the distance between the two vehicles increase.
4. Wrap-up – bring the class together to discuss how the demonstration is like and unlike the expansion of the universe.

Activity #4 Modeling the Expansion of the Universe

This activity was taken from the CPEP Course on the History and Fate of the Universe.

See Appendix C

Activity #5 Stretching of Light Waves with Expansion of the Universe Simulation

See Appendix D

This activity was taken from the CPEP Course on the History and Fate of the Universe.

The microwaves background radiation that is all around us at this time originated as high energy, therefore short wavelength, electromagnetic radiation. However these waves have been passing through space, as space has been expanding, for over 13 billion years, and the waves have been stretched along with the special expansion.

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Appendix A

The Universe Adventure

http://www.cpepweb.org

The History and Fate of the Universe

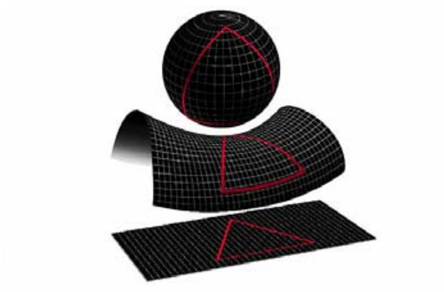
1. Who is known as the grandfather of cosmology? When did he live?
2. What questions does cosmology try to answer?
3. Cosmology is the study of…
4. How far back in time are we looking when we view…
    - The moon?
    - The sun?
    - Saturn?
    - Proxima Centauri?
    - Center of our galaxy?
    - Andromeda Galaxy?
    - The Mice?
    - Oldest Quasars?
    - Cosmic Microwave Background?
5. The light we see now left most recently from…
6. Why can't we see most of the universe?
7. How large (in light years) is our "sphere of the visible universe"?
8. Most of the universe is:
    - Which means that:
9. How old is/are…
    - The Earth?
    - The oldest stars?
    - The universe?
10. Who established the concept of a geocentric universe with concentric spheres for the orbits of the sun and the planets?
11. According to the Copernican model, what was in the center of the solar system?
12. One thing that theories of early cosmologists had in common was that…
13. Two things that affect the force of gravity are:
14. A graph of FORCE vs. MASS looks like…(draw it on another sheet of paper)
15. A graph of FORCE vs. DISTANCE looks like…(draw this one too)
16. What apparent paradox was created by gravity when applied to the universe as a whole?
17. Einstein's Theory of General Relativity states that…
18. The idea that the universe is homogeneous and isotropic (that is, the average number of galaxies per unit volume does not change with distance or direction) is called the…

19. What did Einstein add to his Theory of Relativity to keep the universe static?
20. Gravity should make the universe ________________________.
21. What is Hubble's Law?
22. At the time of the Big Bang, the universe was…
23. What are four reasons why scientists think there was a Big Bang?
24. Which objects do not expand?
25. When light is stretched, it gets…
26. Farther galaxies have greater red shift. This is caused by…
27. The Red Shift is important because…
28. The Red Shift is…
29. The Big Bang is an ____________________, not an ____________________.
30. Since everything in the universe appears to be expanding away from the Earth, are we at the center after all?
31. Where is the center of the universe?
32. What is CMB?
33. Who discovered CMB and when?
34. What has happened to CMB radiation since the Big Bang?
35. Why is CMB significant?
36. Why do we see two "poles" of CMB – a warmer and a cooler one?
37. High temperatures correspond to ____________________ wavelengths and low temperatures correspond to ____________________ wavelengths.
38. Why is the CMB so cold if it's a relic of the hot Big Bang?
39. If we could see radiation from the CMB, what would it look like?
40. What are the current percentages of Hydrogen and Helium in the universe?
41. At higher temperatures, only ____________________ and ____________________ exist.
42. Once a proton and neutron fuse to form deuterium, it has two possible fusion choices. Either ultimately forms a ____________________.
43. Which elements were formed during the Big Bang?
44. Heavy elements form:
45. This is because the conditions necessary for heavy elements include…
46. Why do the properties of the light emitted by stars change?
47. As the universe expands, it appears…
48. Inflation ____________________ the visible universe.
49. Cosmic Inflation did not…
50. Inflation explains why the universe is…
51. After inflation, impurities in the universe are…
52. The universe has cooled enough that a significant amount of energy stays in the form of ____________________.
53. If 1 kg of protons were converted to electricity, how long would that power the USA?
54. How does an antiparticle differ from its corresponding particle?
55. When a particle and its antiparticle collide, their mass is converted into…

56. Why aren’t particle/antiparticle pairs easily produced today?
57. Examples of nucleons include…
58. Nucleons are formed when…
59. In which era did…
Inflation occur?
Deceleration occur?
Dark energy speed up expansion?
Quark/Gluon plasma exist?
Protons and neutrons form nuclei?
Nuclei and electrons begin to create atoms?
Atoms come together to form the first stars and galaxies?
60. ___________________ did not lead to the formation of galaxies.
61. If the universe started contracting inward, it would be called the ___________________.
62. What observations have shown that the expansion of the universe is accelerating?
63. Acceleration of the expansion indicates that gravity is counterbalanced by …
64. A type of matter not made of atoms and nuclei is called …
65. We know dark matter is there because…
66. The elements of ancient cosmology are…
67. To look back in time, we just need to look…
68. To measure the distance or brightness of objects, we use…
69. The light that reaches the Earth’s surface is called the …
70. Two identical stars which have the same luminosity can appear to have very different brightness’ on Earth because…
71. This difference in brightness is the result of …
72. The reason we don’t see stars during the day is…
73. Four wavelengths of observations are…
74. Three famous observatories are…
75. What are three still unanswered questions about the universe?
76. Why is the night sky dark?
77. Olber’s Paradox states that if the universe is infinite then…
78. Might cosmic dust cause the night sky to be dark? Why or why not?

Appendix B

Determining the Geometry of Space: Taken from the CPEP course: History and Fate of the Universe



On a "small" scale (for example, the distances between galaxies), the curvature of our universe is negligible. On the cosmological scale, however, this curvature has a greater effect.

Our universe may have one of three basic shapes: open, closed, or flat. Just as the escape velocity of a planet is determined by its mass and radius, the universe "escape velocity" depends upon its mass and size or critical mass density. Ω_{mass} is the ratio of the actual density of the universe divided by its critical mass density for ordinary matter, Ω_d is the density of dark matter and, Ω_Λ is the cosmological constant, which Einstein invented to represent a force opposing gravitational attraction. Although previously thought to be zero and "Einstein's greatest blunder", the fact that the universe has been found to be expanding at an accelerating rate, has caused renewed interest.

There are several ways to study the shape of our universe. One of these ways is to observe the distribution of galaxies over a wide range of distances.

Observations:

First cut inside the dark lines for 2 patterns of each geometric shape.
Using one of each shape, assemble the universe models.

- For the open universe, tape the pieces together so that the structure looks similar to a saddle.

- For the closed universe, tape the cut edges together so that the shape resembles a hemisphere.

- For the flat universe, there is no need to do anything.

After assembling, carefully observe the distribution of galaxies (or dots) on the surface of each and answer the following questions.

1. For the open universe, how are the galaxies distributed?
   a. There are more galaxies at the center of the pattern.
   b. There are more galaxies at the outside edge of the pattern.
   c. There are the same number of galaxies everywhere.

2. For the closed universe, how are the galaxies distributed?
    a. There are more galaxies at the center of the pattern.
    b. There are more galaxies at the outside edge of the pattern.
    c. There are the same number of galaxies everywhere.

3. For the flat universe, how are the galaxies distributed?
    a. There are more galaxies at the center of the pattern.
    b. There are more galaxies at the outside edge of the pattern.
    c. There are the same number of galaxies everywhere.

For the remaining set, tape only the center of the open universe pieces together.
Leave the other shapes unassembled.
Observe this unassembled set. Is the matter evenly distributed?

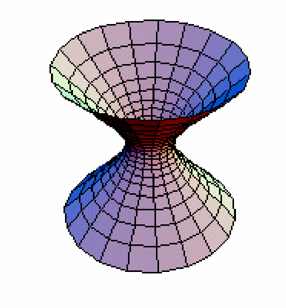
1. For the open universe, how are the galaxies distributed?
    a. There are more galaxies at the center of the pattern.
    b. There are more galaxies at the outside edge of the pattern.
    c. There are the same numbers of galaxies everywhere.

2. For the closed universe, how are the galaxies distributed?
    a. There are more galaxies at the center of the pattern.
    b. There are more galaxies at the outside edge of the pattern.
    c. There are the same numbers of galaxies everywhere.

3. For the flat universe, how are the galaxies distributed?
    a. There are more galaxies at the center of the pattern.
    b. There are more galaxies at the outside edge of the pattern.
    c. There are the same numbers of galaxies everywhere.

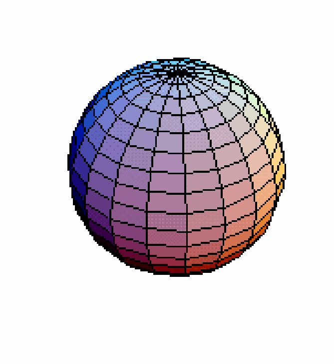
In an open universe

- $\Omega_{mass} + \Omega_d + \Omega_\Lambda < 1$
- The sum of angles in a triangle $<180^{o}$
- The circumference of a circle $> 2\pi r$
- Negative curvature
- There appear to be more galaxies at great distances than nearby
- Saddle shape
- Infinite
- Continued expansion



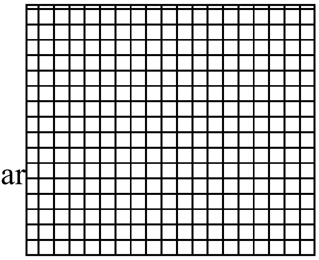
In a closed universe

- $\Omega_{mass} + \Omega_d + \Omega_\Lambda > 1$
- The sum of angles in a triangle $>180^{o}$
- The circumference of a circle $< 2\pi r$
- Positive curvature
- There appear to be less galaxies at great distances than nearby
- Spherical shape
- Finite
- Expansion will halt (collapse into the “Big Crunch”)



In a flat universe

- $\Omega_{mass} + \Omega_d + \Omega_\Lambda = 1$
- The sum of angles in a triangle $= 180^{o}$
- The circumference of a circle $= 2\pi r$
- No curvature
- There appear to be the same number of galaxies at great distances and near
- Flat shape
- Infinite
- Continued expansion



Appendix C

Modeling the Expansion of the Universe: Taken from the CPEP Course: History and Fate of the Universe

Part I

1. Cut a piece of elastic to a length of approximately 30 cm. (A rubber band may be used in place of the elastic, but the initial length and distances may need to be scaled down.)
2. Without stretching the elastic, flatten the elastic next to a meter stick. Place paper clips (galaxies) every 5 cm (at 5,10,15, and 20).
3. While keeping the line of galaxies next to the meter stick, keep one galaxy at a noted position while stretching the elastic until the next galaxy (nearest the "stationary" galaxy) has traveled 1 cm (time 1). Note the positions of each of the galaxies on the chart below.
4. Stretch the elastic again so that the galaxy nearest the "stationary" galaxy has traveled 2 cm (time 2). *
5. Try again for 3 cm (time 3). *

*Be sure to check the positions of the galaxies before each stretch and readjust if necessary.

Galaxy	X_0 Position at time 0 (cm)	X_1 Position at time 1 (cm)	Distance moved (X_1-X_0) (cm)	X_2 Position at time 2 (cm)	Distance moved (X_2-X_1) (cm)	X_3 Position at Time 3 (cm)	Distance moved (X_3-X_2) (cm)
1	5	5	0	5	0	5	0
2	10	11	1	12	1	13	10
3	15						
4	20						
5	25						

Is there a pattern in the distances moved? Describe.

Part II

Select the second galaxy to be the stationary galaxy. Repeat steps 3, 4, and 5. You may need a partner to hold the galaxy stationary while you stretch the ones on either side.

Galaxy	X_0 Position at time 0 (cm)	X_1 Position at time 1 (cm)	Distance moved (X_1-X_0) (cm)	X_2 Position at time 2 (cm)	Distance moved (X_2-X_1) (cm)	X_3 Position at Time 3 (cm)	Distance moved (X_3-X_2) (cm)
1	5	4	-1	3	-1	2	-1
2	10	10	0	10	0	10	10
3	15	16	1	17	1	18	1
4	20						
5	25						

Is there a pattern in the distances moved? How do these “distances moved” compare with those in Part I?

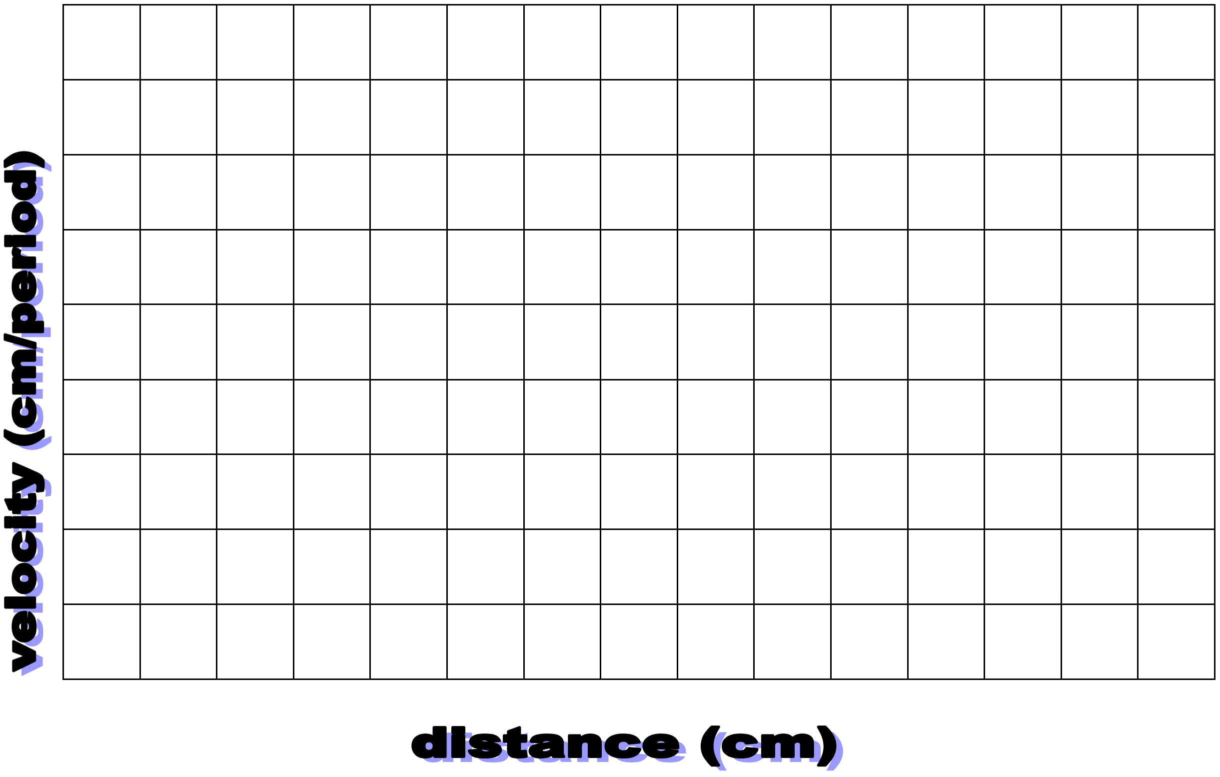
Do you think the same pattern would be noticed if another galaxy was chosen to be the stationary galaxy?

How do the speeds of the galaxies (distance moved per time period) relate to the position?

The galaxies farther away from the stationary galaxy move _______________ those close to the stationary galaxy.
a. faster than
b. slower than
c. the same speed as
d. unrelated to
Would the expansion of the universe look different if we changed our viewing location?

Considering your answer to the question above, is our location “special”? Are we at the center of the expanding universe?

Using your data from Part I, plot the initial positions (X_0 values) on the x-axis and the distance moved (X_1-X_0) per time period (the velocity) on the y-axis.



According to Hubble’s Law ($v_r = H_0$ x d_G where v_r is the velocity of recession, H_0 is the Hubble constant, and d_G is the distance to the galaxy) the speed at which galaxies move away from each other is proportional to their distance. v_r / d_G (or the slope of the velocity vs. distance graph) is the Hubble constant. Hubble’s value of the slope was approximately 500 km/s/Mpc. The current value is approximately 72 km/s/Mpc.

What was the value of slope for your universe (your Hubble constant)?
______________________________cm/period/cm

Appendix D

Stretching of Light Waves with Expansion of the Universe Simulation

The microwaves background radiation that is all around us at this time originated as high energy, therefore short wavelength, electromagnetic radiation. However these waves have been passing through space, as space has been expanding, for over 13 billion years, and the waves have been stretched along with the special expansion.

This can be simulated with a Slinky in two ways as described below.

Procedures:

I. Space model
  1. Find a ceiling support or other support high enough that a large Slinky can be attached at the top only while the bottom of the Slinky doesn't quite reach the floor. Attach one end of the Slinky to the support.
  2. Students can observe that the coils of the Slinky are closer together at the bottom than at the top. This models the expansion of space over time in one dimension. The bottom part of the Slinky represents space shortly after the Big Bang. Things like atoms and the larger structures like galaxies that formed in the first few hundred million years after the Big Bang were relatively close together like the rungs of the Slinky. Time after the Big Bang is modeled as increasing in the upward direction along the Slinky. The top of the Slinky models space at recent time. The expansion of space has moved large structures, such as clusters of galaxies far apart like the rungs near the top. This increasing separation would also have occurred with electromagnetic waves as they expanded with space. In this sense the separations between coils at the bottom of the Slinky model the wavelengths of the radiation that eventually became the microwave background that we measure today. As time is imagined to progress from the past to the present, these wavelengths are seen to increase.

II. Traveling wave model
  1. Actual waves can be sent along the Slinky from the bottom to the top. Have someone send waves from the bottom by quickly

moving the Bottom rungs of the Slinky back and forth sideways with a constant rhythm. Note that these are transverse waves. Longitudinal waves could also be sent up the Slinky, but these are harder to observe, and light waves are also transverse.

2. If a video-camera is available, have someone film the resulting wave motion. The film can then be viewed frame by frame to see that the wavelengths are increasing as the wave moves upward. This is a more literal modeling of the increase in wavelength as electromagnetic radiation moves through expanding space.

Limitations of the model:

The reason that wavelengths increase in part II is that wave speed increases as the wave moves up on the Slinky. This happens because wave speed along a spring is found from the square root of tension divided by mass per unit length. The tension is highest near the top, and the mass per unit length is less near the top. Both parts of this combination favor a higher speed at the top. Since wave speed also equals frequency times wavelength, and frequency is being held nearly constant, wavelength will be greater at the top.

The problem then is that the speed of light doesn't change in local space as the wave speed of the Slinky wave does. The Slinky model only simulates the increase in wavelength.

Note that this activity could be "sprinkled" into a unit on waves. Students could measure a typical tension near the top and another near the bottom with a spring scale, and use the number of rungs per length to represent the mass per unit length and calculate the relative velocities and wavelengths between top and bottom waves.