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To accompany the peer-reviewed article by Paul J. Steinhardt, Ph.D.
"The Endless Universe: Introduction to the Cyclic Universe" (May 2002)
http://www.actionbioscience.org/newfrontiers/steinhardt.html

Cyclic Universe: Worlds Without End (Mar. 2003)

Lesson by Ronald Brian Watts, Ph.D., Professor, Dept. of Biology & Chemistry, CEGEP De La Gaspesie et Des Iles, Gaspe, QC, Canada

Grades & Levels:

- **Handout 1**: senior high school
- **Handout 2**: undergraduate, year 1-2

Time Recommendations:

- 2-3 days for article review and discussion
- up to 2 weeks for activities in Student Handout 1
- up to 4 weeks for activities in Student Handout 2

NSES (USA) Content Standards, 9-12:

- NSES 1.1. Unifying Concepts & Processes: systems, order, & organization
- NSES 2.2. Science and Inquiry: understanding about scientific inquiry
- NSES 5.3. Earth & Space Science: origin & evolution of the earth system
- NSES 5.4. Earth & Space Science: origin & evolution of the universe

Note: View the NSES content standards on this site to choose other curricular applications for additional activities at: http://www.actionbioscience.org/educators/correlationcharts.html

Learning Objectives: Students will…

- compare and contrast the Big Bang Theory and the Cyclic Universe Model
- describe how Superstring Theory and the Cyclic Universe Model together may provide an explanation of the Universe's origins
- understand basic properties of the universe which make life possible
- evaluate ideas about the origin of the universe as to their scientific value

Key Words Include:
Big Bang, Big Crunch, black hole, branes, compact manifold, cosmic microwave background, cosmology, dark energy, ekpyrotic model, entropy, general relativity, hypothesis, inflation, inflationary model, M Theory, paradigm, singularity, superluminal expansion, Superstring Theory, theory, Time's Arrow

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Preparation

Article Discussion:

- Distribute or ask students to download and read the article by Steinhardt at http://www.actionbioscience.org/newfrontiers/steinhardt.html
- Follow the reading with questions about the article in the "Article Discussion" section. Students can answer questions orally in class, brainstorm answers in groups, or complete questions as a written assignment.

Student Handouts:
Follow the article discussion with project assignments suggested in the handouts. These can be assigned as an individual or group activity.

Supplementary Handout:
This handout includes a glossary and a select list of literature resources. The latter may be useful to students for their research. Additionally, students can refer to "useful links" in *Educator Resources* at the end of Steinhardt's article for online resources.

For Educators: Article Discussion

About the article by Paul J. Steinhardt, Ph.D.:
"The Endless Universe: Introduction to the Cyclic Universe"
http://www.actionbioscience.org/newfrontiers/steinhardt.html

Content Questions
1. What theory is considered to provide the best explanation of the origin and evolution of the universe?
2. What are the four statements of the Big Bang Theory?
3. What is the effect of so-called "dark energy" on the universe?
4. How does the Cyclic Universe Model differ from the Big Bang Theory?
5. What 4 questions does the Cyclic Universe Model address that cannot be answered by the Big Bang Theory?
6. Describe the main features of one cycle of the universe according to the author's hypothesis.
7. What is the Big Crunch? How, in the author's view, does it replenish the universe?
8. In what sense does Superstring Theory lead physicists to believe that our conception of the Big Bang and Big Crunch may be illusions?
9. What are the two primary features of M Theory? How do they relate to the Cyclic Universe Hypothesis?
10. Why does the author appear to find the Cyclic Universe idea so appealing?

Extension Questions
1. Why do most scientists consider the Big Bang Theory to be the best current theory of the origin and evolution of the universe?
2. List 3 other ideas proposed by scientists for the origin and evolution of the universe. Which of these ideas are or are not scientific theories? Why?
3. In what way could the Cyclic Universe Model be considered a more inclusive explanation of the origin and evolution of the universe than the Big Bang Theory?
4. What implications would a cyclic universe have to the existence of life in the universe? Do you think that this would make life elsewhere more or less probable? Why or why not?

Personal Viewpoint Questions
1. Do you think that scientific investigations of our current universe can tell us anything about the beginning of the universe? Of what relevance are such studies to our lives?
2. If further research provided supporting evidence for the Cyclic Universe Model, then would this hypothesis be of concern to us in our daily lives? Why or why not?

Student Handout 1

1. Survey on "Origin of the Universe"

Together with 2 or more students, conduct a survey.

- With Dr. Steinhardt's article as a source, prepare a questionnaire containing 10 to 15 questions on the subject "Origin of the Universe."
- Randomly choose 30-40 subjects and interview them using the questionnaire. (Divide the subjects among team members. For example, if your team consists of 4 members, each member can interview 10 subjects each.)
- After all interviews are conducted, summarize the team's results in a report.

2. Space Biology Talk Show

- With a partner, prepare a 10-minute radio talk show about biologists' interest in understanding the universe. For example: Is it relevant for biologists to concern themselves with questions such as "How did the universe start?" and "Could life exist in other universes with slightly different values of critical constants?"
- Present the talk show live in class or record it on audiotape.

3. The Universe on the Internet

Perform a web search on one of the topics below. Prepare a brief two or three sentence description of each pertinent web site, page, or article found. You may wish to print copies of the most significant information found to present to your class.

- What properties of the Universe permit life to exist?
- Is our Universe the only universe or is there a larger Cosmos?
- How are the three "origin of the universe" ideas -- Big Bang Theory, Cyclic Universe Hypothesis, and Steady-State Universe Model -- rated by scientists?
- Are there any other scientific ideas about the origin of the universe? What are they?
- What is required of a truly scientific model of the origin of the universe? How could we test it?

4. Is It Scientific?

As a volunteer at a planetarium, you've been asked to prepare a poster display for the public. Your display should focus on:

- a comparison between the Big Bang Theory and the Cyclic Universe Hypothesis
- an explanation for why both ideas can be considered scientific and which is more likely

5. Universe Glossary

You have a great idea for a children's book -- an illustrated glossary about the universe for middle school students. Prepare sample pages of your glossary for a publisher.

- Choose 10 words. For example: Supernovae, Black Holes, White Dwarfs, Pulsars, Dark Matter, Cosmic Rays, Gamma-Ray Bursts, Quasars.
- In your own words, write a one- or two-line definition for each word.
- Find graphics on the Internet or in literature. Draw or paste the graphics in your glossary. Be sure to credit your sources.

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Student Handout 2

1. Interview an Astronomer or Cosmologist

If you live in a town with an astronomy club, a college with an astronomer on staff, or a university with an astronomy department, contact them and inquire if you might interview one of their members or faculty who has an interest on the topic of the origin of the universe.

- Contact your subject and explain that you would like to conduct a brief interview (no more than an hour in length if possible) as a course project.
- If he or she agrees, then prepare a list of questions to submit to your subject two weeks before the agreed upon interview date.
- Consider videotaping your interview. Be prepared to take notes.
- Afterwards prepare a summary or edit your videotape to present to your class.

2. Poster Display

Prepare a poster display or science-fair type of kiosk illustrating one of the topics below. Find or create suitable illustrations to complement each idea you present.

- The historical development of ideas about the Origin of the Universe
- A comparison of the scientific support for each of the three main ideas about the Origin of the Universe: *Big Bang Theory, Cyclic Universe Hypothesis, and Steady-State Universe Model*
- The properties of our universe that seem to permit the existence of life and ideas about what would happen if these properties were different
- The main points of Dr. Steinhardt's article

3. The Theory of Everything?

As a participant at a scientific conference, you will present your views on why string theory may be the ultimate theory – "the theory of everything." Prepare a presentation that includes information about:

- What are the basic principles of string theory? (e.g., particles, dimensions, space, time, etc.)
- Are there variations of the theory? What are they?
- Who are some scientists involved in major breakthroughs in the theory and what did they discover? (e.g., Andrew Strominger)
- What particular difficulty of modern physics (not necessarily related to theories of the universe's origin) does it seek to (or seem to) resolve?
- Why is it particularly appealing to cosmologists that Superstring Theory and the Cyclic Universe Model seem to complement each other so well?

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Supplementary Handout

A. <u>Resources</u> The following books and articles will be useful as sources for background information or research ideas on the topic of *Origins of the Universe.* The list is by no means complete, but should serve as a starting point for research.

» FERRIS, Timothy, 1997. **The Whole Shebang: A State-of-the-Universe(s) Report,** Simon & Schuster. New York, NY, USA, 400 pgs. [ISBN: 0-684-81020-4]
The author set out to summarize our understanding of the universe as the second millennium drew to a close.
» FOLGER, Tim, 2002. "**The real Big Bang**," *Discover* 23(12): 40-47, [ISSN: 0274-7629] (December 2002 Issue)
Examination of events millions of years before the Big Bang was the beginning of our universe.
» GREENE, Brian, 1999. **The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory,** W.W. Norton & Company, New York, NY, USA, 461 pgs. [ISBN: 0-393-04688-5]
Discussion of the fundamentals of modern physics as relevant to cosmology.
» HAWKING, Stephen, 2001. **The Universe In A Nutshell,** Bantam Books, New York, NY, USA, 216 pgs. [ISBN: 0-553-90202-X]
Illustrated book on the frontiers of physics and cosmology in a very understandable form.
» LEMLEY, Brad. 2002. "**Guth's grand guess**," *Discover* 23(4): 32-39, [ISSN: 0274-7629] (April 2002 Issue)
This article explains Alan Guth's cosmic inflation hypothesis and how it strengthens the Big Bang Theory.
» REES, Martin, 1999. **Just Six Numbers: The Deep Forces That Shape the Universe,** Basic Books, (Perseus Books Group), London, UK, 185 pgs. [ISBN: 0-965-25654-5]
Examination of how our universe is determined by the values of six fundamental constants.
» REES, Martin, 2001. **Our Cosmic Habitat**, Princeton Univ. Press, Princeton, NJ. USA, 222 pgs. [ISBN: 0-965-42089-2]
Rees presents the fundamental principles and character of our cosmos, with a brief section on life in the universe.
» RENNIE, John (Ed.) 2002. "**The once and future COSMOS**," *Scientific American* Sp. Edition 12 (2). [ISSN: 1048-0943]
A collection of articles by preeminent astronomers, cosmologists, and physicists.
» SWEITZER, Jim, 2002. "**Do you believe in the Big Bang?"** *Astronomy* 30(12): 34-39. (Oct. 2002 issue). [ISSN: 0091-6358]
This article outlines five reasons why everyone should believe in this theory. There is also an excellent brief sidebar explaining what a "Theory" is in science and how cosmological scientific theories are tested by evidence.

B. <u>Glossary</u>

Big Bang: The currently most favored theory about the origin of the universe. The universe including all matter and energy within it sprang into being about 15 billion years ago in a colossal "explosion" of space-time. This was followed quickly by a brief period of rapid expansion (Guth's Inflationary Period). Eventually, about 100 million years later, galaxies, stars, and planets began to form and the universe, as we know it, began. (Adapted from Steinhardt 2002)

Big Crunch: A possible event in the far distant future of the universe when all matter and energy will collapse into a singularity. The event will resemble the reverse of the Big Bang. The Cyclic Universe Model predicts that this will be followed immediately by another Big Bang event.

Black Hole: A region of space from which nothing, not even light, can escape because gravity is so strong. (Hawking 2001)

Branes: Any of the extended objects that arise in String Theory. A one-brane is a string. A two-brane is a membrane. A three-brane has three spatial dimensions, etc. (Greene 1999)

Compact Manifold: An infinitely small multidimensional surface or volume postulated by String Theory and M Theory to be the state in which the 7 or 8 "extra' dimensions of our universe exist beyond the range of direct detection. (Adapted from Greene 1999)

Cosmic Microwave Background: Microwave radiation that appears to come from all directions in the universe. It appears to have been produced during the Big Bang and to have cooled and thinned as the universe expanded. This is one of the most significant pieces of evidence for the Big Bang. (Adapted from Greene 1999)

Cosmology: The study of the origins and evolution of the universe. The science concerned with discerning the structure and composition of the universe as a whole. Cosmology builds upon astronomy, astro-physics, particle physics, and various mathematical approaches. (Adapted from Ferris 1997)

Dark Energy: A form of non-visible energy that is postulated to be causing a rapidly increasing expansion of the universe today. Observations of explosions of super-massive stars (supernovae) in very distant galaxies are the primary evidence for this form of energy.

Ekpyrotic Model: According to this model, the universe was created in a sudden burst of fire, not unlike the collision between three-dimensional worlds in the model of Dr. Steinhardt and his associates.

Entropy: A measure of the disorder of a physical system. The number of rearrangements of the components of a system that leaves its macroscopic appearance unchanged. (Adapted from Greene 1999 and Hawking 2001)

General Relativity: A theory postulated by Einstein in which the laws of the universe are expected to remain the same no matter what the state of motion of the observer. In this theory, Einstein explained gravity as a property of four-dimensional space-time. (Adapted from Hawking 2001)

Hypothesis: In science, a statement of explanation proposed on the basis of preliminary observation and the scientist's current state of knowledge. An idea or explanation not yet tested by systematic observation nor experiment.

Inflation: When used in cosmology, a sudden instance of enormous expansion.

Inflationary Model: The idea that shortly following the Big Bang, the universe experienced a sudden inflationary expansion at many times the speed of light and to many times its initial size. As proposed by Alan Guth, it reconciles the initial Big Bang Hypothesis with certain observed properties of the universe.

M Theory: A theory uniting all five string theories as well as supergravity within a single theoretical framework. It appears to involve eleven space-time dimensions, although many of its detailed properties have yet to be worked out. (Adapted from Greene 1999 and Hawking 2001)

Paradigm: A wide-ranging philosophical or theoretical framework of thought and approach providing a powerful explanatory focus for further research. Most modern physicists, for example, view Einstein's theory of relativity as providing a "paradigm" for research into cosmological phenomena while most modern biologists accept evolutionary theory as the paradigm guiding research into the origins, history, and workings of life.

Singularity: A point of infinite curvature of space where the equations of relativity break down (Ferris 1997). Location where the fabric of space suffers a devastating rupture (Greene 1999). A point in space-time where the spatial curvature becomes infinite (Hawking 2001).

Superluminal Expansion: Expansion of the universe at greater than light speed. This occurred during the inflationary episode immediately after the Big Bang.

Superstring Theory: String theory, which incorporates Supersymmetry (Greene 1999). Supersymmetry relates the properties of the elementary particles to their spin (Hawking 2001).

Theory: In the sciences, this is an idea or hypothesis that has been thoroughly tested by experiment and/or systematic observation and has been strongly supported by that evidence. A theory can provide a powerful explanation for fundamental phenomena but is always open to re-testing and revision. Like a hypothesis, it is falsifiable.

Time's Arrow: A term often used to refer to the seemingly one directional flow of time from the past, through the present, and into the future. Physicists have classically related the flow of time to the Second Law of Thermodynamics, which generally states that the total disorder (or entropy) of the universe is increasing. Recently, theoretical physicists have argued that the flow of time may be an illusion, although the second law of thermodynamics is not.

References used to formulate glossary definitions …

» FERRIS, Timothy, 1997. **The Whole Shebang: A State-of-the-Universe(s) Report,** Simon & Schuster. New York, NY, USA.
» GREENE, Brian, 1999. **The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory,** W.W. Norton & Company, New York, NY, USA.
» HAWKING, Stephen, 2001. **The Universe In A Nutshell,** Bantam Books, New York, NY, USA.
» STEINHARDT, Paul J., 2002. **A Brief Introduction to the Ekpyrotic Universe,** http://feynman.princeton.edu/~steinh/npr/ (accessed Mar. 2003).