CASE-BASED COURSE PLAN
Scientific Inquiry Work Group (2001-2002)

INTRODUCTION

A group of volunteers from the Scientific Inquiry program's contributing faculty members met several times during summer break 2001 to discuss the Scientific Inquiry course (SCI 105) – an ad hoc program curriculum committee. This group's organizing goal was the production of additional case study materials to support the Scientific Inquiry course. Early deliberations examined the program's failure to adopt a common core text (for AY 2001-2002) and the trend (noted from anecdotal evidence only) toward increasing the case study content in SCI 105 course plans. These deliberations led the faculty group to refocus its goal as the assembly of a case study set representing the coverage of the course's learning objectives without reliance on a core text. Additionally, the group sought to link these case studies through a common theme and chose "Origins," referring to the fundamental structural models in the scientific disciplines. The table below outlines the prototype course plan from which the faculty group developed the progressive set of learning objectives identified in the teaching notes for each of the new case studies.

COURSE PLAN

Case Duration	Case Description
Up to 1½ Weeks	Case 1: What Do We Know? *(Opening Statements Case Study)*
About 2 Weeks	Case 2: How Do We Know? *(Debate Involving Science)*
2 to 3 Weeks	Case 3: Divergence in Ways of Knowing *(Authoritative, Philosophic, and Scientific Models in Cosmogony)*
1½ to 2 Weeks	Case 4: Why Do We Think that the Universe Is Expanding? *(Edwin Hubble's Beautiful Cosmology)*
1 to 2 Weeks	Case 5: Organic Soup? *(Chemical Origins of Life)*
2 to 2½ Weeks	Case 6: Five Micro-Evolutionary Points *(Experimental Design in Micro-Evolution)*
About 4 Weeks	Case 7: Extended Case Study Chosen by Instructor Example Extended Case Study Texts Include: *Science on Trial* (Marcia Angell) *The Double Helix* (James D. Watson) *Deadly Feasts* (Richard Rhodes) *Oxygen* (Carl Djerassi and Roald Hoffmann)

DIRECTOR'S COMMENTARY

This prototype course plan is not a mandate for SCI 105 course content. The specific cases presented might be implemented in course plans individually (not necessarily as a set) to provide coverage of the associated learning objectives. The work group assembled this set as an example of how the learning objectives for SCI 105 might be distributed across a set of case studies drawing content from different scientific disciplines. In preparing them, we were especially interested in the logical progression of course segments: The first two cases introduce foundational concepts about the nature of science and scientific knowledge; the next two address the development of scientific models; and the next two cover experimental design issues. At least one extended case study is suggested to conclude the course by addressing the social context of science.

Hopefully this course plan (and the accompanying set of case studies) will help to clarify and support the notion that all SCI 105 course offerings will continue to share some common ground: Pedagogy and learning objectives. The case study instructional method lends itself to cooperative learning, and the teaching notes for each of the proposed case studies suggest discussion topics and in-class activities through which small student groups can approach that cooperative learning. The SCI 105 learning objectives are discipline independent, reflecting what I have called the meta-content of this course. (The SCI program objectives are briefly outlined at the program's web page, **http://sci.mercer.edu**, and more detailed objectives are in the teaching notes for these case studies.) In other words, we don't have any specific content requirements from any area of science. The learning objectives from any of the case studies above might be just as easily approached within the context of an appropriate substitute case from any of the scientific disciplines.

WORK GROUP

Scientific Inquiry Work Group (2001-2002) members were: Jose Balduz (*balduz_jl@mercer.edu*), Frank Dane, Linda Hensel (*hensel_ll@mercer.edu*), Curtis Herink (*herink_cd@mercer.edu*), and Dale Moore (*moore_de@mercer.edu*).

CASE 1: WHAT DO WE KNOW? (UP TO 1½ WEEKS)

Background: This case is based on John Shepherd's **Opening Statements** case notes from the Scientific Inquiry Program faculty web page (http://sci.mercer.edu/faculty/fac.htm). David Nelson originated the case idea during the Summer 1997 Scientific Inquiry workshop. This case is kicked off by asking the students to review a set of statements, and rank them according to their own certainty about the correctness of the statements.

Reading: There are no required readings to use this case for 1-2 class periods of introductory discussion. However, some of the suggested discussion items might fit well with readings from J. Bronowski's *Science and Human Values* (1956). Notes under the Case Plan below include optional reading assignments from Bronowski to extend the case.

Other optional readings might include selections from *Science and Its Ways of Knowing*, edited by Hatton and Plouffe (Prentice Hall, 1997), especially George F. Kneller's "A Method of Inquiry" (pp 11-24) and Henry H. Bauer's "The So-Called Scientific Method" (pp 25-36). These readings might be used as homework assignments. The students might be required to read the essays and write an appropriate paragraph response. An example leading question might be: "Why does information that is gathered by scientists have such a high value in our society?"

LEARNING OBJECTIVES

(1) Introduce scientific information as a distinct type of knowledge.
(2) Provide the concept of verifiability as a criterion separating belief from scientific information.
(3) Lead students to discover that verifiability requires experimental design.
(4) Prepare students for the cases that follow by establishing the notion of several different bases for knowledge.

"WHAT DO WE KNOW?" ITEMS

This list of sample items (from John Shepherd and Tom Huber) demonstrates the variety of statements that students have been asked to evaluate in this case. Typically, the class has been presented with a set of ten such items.

1. Jesus Christ is the son of God.
2. Lee Harvey Oswald was John F. Kennedy's lone assassin.
3. A molecule of water contains two atoms of hydrogen and one atom of oxygen.
4. Smoking tobacco cigarettes causes cancer.
5. A stitch in time saves nine.
6. $E = mc^2$
7. Shakespeare was Britain's greatest playwright.
8. Spiritual existence continues after a person's body dies.
9. The best movie of 1997 was The English Patient.
10. The sum of the angles of any triangle is 180 degrees.
11. Since Theodore Kaczynski is mentally ill, he shouldn't be executed for the Unabomber murders.
12. Walls do not a prison make, nor iron bars a cage.
13. John Shepherd is the oldest person in the room.
14. Timothy McVeigh and Terry Nichols were the only two persons directly involved in the Oklahoma City bombing.
15. Better late than never.
16. Silicone gel-filled breast implants cause autoimmune diseases.
17. Impressionist paintings are better than Cubist paintings.
18. Mary was a virgin when Jesus was born.
19. Walt Whitman was America's greatest poet.
20. Americans of Asian descent are harder working than Americans of European descent.
21. Red wines taste better than white wines.
22. Human immunodeficiency virus (HIV) causes acquired immunodeficiency syndrome (AIDS).
23. The pace of life in the South is better than that in the Northeast.
24. Mohammed is the greatest prophet of the God of Abraham.

CASE PLAN

Discussion 1: In initial class meetings, our students will need to acclimate themselves to the discussion group format and to the other people in their groups. The discussion and ranking of a set of items from the list above provides a good icebreaker activity.

Divide the class into small discussion groups and present each person with a copy of your list of ten items, representing a variety of statements. Ask that each person rank the items in order of increasing **certainty**, then ask that the groups discuss their rankings among themselves and create single lists representing as best they can the group rankings for certainty. (Disagreements should lead the groups to develop some method for reconciling differences of opinion within the group.) Discussion leads with which to follow up include:

1. How did each group define certainty? How might certainty be measured? Can certainty be measured (or measured to the same degree) for every statement on the list? [Prompts might include example criteria for certainty based on faith, opinion, logic, etc. Instructors might ask students to consider which, if any, of these criteria are more valuable as a prelude to Discussion item 3, below.]

2. *Which statement did you rank as most certain? Why? Least certain, and why?*

One option here would be to review the full rankings made by each group, leading them to address discrepancies between rankings in terms of what evaluation criteria were used and how these were weighted when assigning the rankings.

3. Optionally, hand out (or else list at the board) the Hunter Lewis' list of Six Ways of Assigning Values (included with the Schemes below as the **Lewis Scheme**.) Ask the students:

Please use this list of items to describe how you evaluated your certainty in each of the ten statements. For each statement, choose one or more of these sources to indicate the origins of your certainty.

This is the first approach to the notion of multiple types of knowledge, or ways of knowing. The objective is to begin to move students toward using evaluation criteria appropriate to the type of knowledge being evaluated. The movement is continued with the next discussion lead.

Other options here might include looking at other schemes for differentiating types of knowledge. Four possible schemes are listed below with references. The **Consistency Test Scheme** is a summary of the branching pathway that will be considered in **Case 3** with respect to the development of the science of cosmology from pre-scientific noetic bases.

4. *Discuss with your group mates: What would it require to increase your certainty about each statement? Please be as specific as possible, proposing illustrative examples where necessary.*

The motive behind this question is twofold: Hopefully, students will begin to propose rudimentary experiments. This will open discussion to include the notion of experimentation and the distinction of scientific knowledge. Also, students might note that some of the statements don't lend themselves to obvious experimentation – statements taken on faith or as common sense 'laws' would be more difficult to verify by experiment. Statements of very specific events for which there are no observational records would be impossible to verify by experiment.

Homework: It is unlikely that thoughtful and complete responses will be drafted for each item on the "What Do We Know?" items list before the end of the first class period. Possible homework would be the completion of discussion question **4** (proposed experiments for each of the list items).

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Discussion 2: Complete small group discussion on: *What would it require to increase your certainty about each statement?* An appropriate wrap-up here might include whole class discussion to compare the groups' proposals. Brainstorming to list the criteria for **verifiability** as well as some preliminary definition for **experiment** might establish lines for further discussion (this period) or for follow up in the next case study (**Case 2**).

Optional Activity: To establish the connections between verifiability and experimentation, especially the testing of models' predictions, it might be appropriate to include an in-class activity such as **Buret Races**. [The Buret Races mini-case is described on the Scientific Inquiry Program faculty web page (http://sci.mercer.edu/faculty/fac.htm) with case notes from John Shepherd and Caleb Arrington. Alternate mini-cases to verify a model by testing a prediction would also be appropriate. Examples from the Scientific Inquiry Program faculty web page include: Using the simple pendulum mini-case with students asked to make predictions about results when changing string length; and the organic molecules cards mini-case (from Mendeleev's Periodic Table case with case notes by Tom Huber) with students asked to make predictions about boiling point, ΔH, etc.]

Optional Reading Assignment: As noted above, discussions on multiple ways of knowing fit well with Bronowski's essays – especially "The Creative Mind" and "The Habit of Truth." [J. Bronowski, *Science and Human Values*, Harper & Row Publishers, 1956.]

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Subsequent Discussions: Subsequent discussion for the extended version of this case would focus on the readings from Bronowski. To tie the readings with this case's learning objectives, students might be asked to construct the **Bronowski Scheme** (paraphrased in the scheme sets below) for differentiating types of knowledge. From this scheme, it becomes more obvious that evaluation of knowledge by certainty isn't really appropriate to a large class of knowledge (essentially the experiential half of the Bronowski Scheme). Further discussion might include asking students to propose alternate criteria by which types of knowledge are evaluated – perhaps returning to the Lewis Scheme and/or revisiting the list of statements with which this case began. Further discussion might also involve items from the optional readings suggested above.

SCHEMES FOR DIFFERENTIATING TYPES OF KNOWLEDGE

Ziman Scheme:

1. Material domain – external world of observational knowledge
2. Mental domain – internal world of constructed or intellectual knowledge
3. Noetic domain – social world of collective knowledge

From: John Ziman, *Reliable Knowledge*, Cambridge University Press, 1978, p106.

Bronowski Scheme:

1. Observation – the physically observable world (objective)
2. Science – recreation of the observable world
3. Emotion – the personally experiential world (subjective)
4. Art – recreation of the experiential world

From: J. Bronowski, *Science and Human Values*, Harper & Row Publishers, 1956, p27.

Lewis Scheme:

1. Authority – accepting knowledge from someone else
2. Deductive logic – knowledge derived from internal consistency tests
3. Sense experience – direct knowledge
4. Emotion – knowledge from feeling
5. Intuition – unconscious (but unemotional) thinking
6. Science – knowledge from specific technique of testing

From: Hunter Lewis, *A Question of Values*, Harper Collins, 1990, pp10-11.

Consistency Test Scheme:

1. Authority – accept knowledge consistent with accepted authority
2. Logic – accept knowledge with internal consistency (logically consistent)
3. Observation – accept knowledge with external consistency (models or theories based on observation)

CASE 2: HOW DO WE KNOW? (ABOUT 2 WEEKS)

Background: This case study is based on a **Debate Involving Science**, in this case "Evolution and Creationism" as described by Michael Shermer in his book, *Why People Believe Weird Things*. Shermer is the publisher of *Skeptic* magazine, the director of the Skeptics Society, the host of the Skeptics Lecture Series at the California Institute of Technology, and an adjunct professor at Occidental College.

[**Suggested Instructor's Reference:** For some background reading on evolutionary theory and the Big Bang model (another creation-related scientific theory in conflict with creationism, mentioned in this case study) SCI 105 instructors might use James Trefil and Robert M. Hazen's *The Sciences: An Integrated Approach, 2nd Edition*, New York: John Wiley & Sons, 1998, esp. CH15 "Cosmology" and CH25 "Evolution."]

Case Reading: Michael Shermer, *Why People Believe Weird Things: Pseudoscience, Superstitions, and Other Confusions of Our Time*, New York: W.H. Freeman & Co., 1997, pp 125-172. (An inexpensive paperbound text that might be included in the course texts.)

LEARNING OBJECTIVES

(1) Introduce the (sometimes-contentious) relationship between scientific knowledge and other types of knowledge or beliefs. Address the social context of knowledge.
(2) Present debate in science as a part of normal scientific communication contributing to consensus building within the scientific community. (Scientific knowledge is part of a noetic domain – it is social knowledge.)
(3) Reinforce that verifiability requires some type of experimental design.
(4) Introduce the limitations of scientific knowledge: Scientific models have quantifiable certainty, but it is always less than 100%. Scientific models might not be appropriate for some questions.

READING SUMMARY

CH9: Introduces the debate between creationists and evolutionists within the context of a specific debate between Duane T. Gish (Institute for Creation Research) and the author. Presented in fairly adversarial context, this chapter will hopefully get students' attention, but it might incite them to begin debating amongst themselves.

CH10: With a point-by-point presentation, this chapter can be used as an extension of the previous case. Hopefully, students will critically evaluate both the creationism points and the author's evolution-based responses. They must ask, "Do these arguments meet the requirement of verifiability?"

CH11: This chapter shifts the debate to a legal venue. The issue: Evolution and creationism in public school curricula. With the inclusion of this chapter, this case approaches not only the interaction between science and religion, but also between science and law (or, more generally, science as a criterion for public decision making). [Note that science in public decision making is also of primary importance for the extended SCI 105 case study involving Marcia Angell's *Science on Trial* – described on the Scientific Inquiry program's faculty web site, http://sci.mercer.edu/faculty/fac.htm.]

CASE PLAN

Reading 1: Assign CH9 from Shermer.

Discussion 1: The first day of discussion should familiarize the students with the topic of this particular debate and with both sides. Several leading questions are provided below that might be used for whole-class discussion or to initiate discussion within small groups. (Obviously, with a topic of this magnitude, some care must be exercised to keep discussion civil and to encourage students to keep their criticisms positive to avoid inappropriate and/or inadvertent offenses.)

· Why did the author enter into a debate on this issue? Is the author a Christian? A religious person (of any faith)? An anti-religious person?
· How did the author describe his debate strategy?
· Why did the author read parts of the Biblical story of creation to the audience? (How might the Biblical story of creation be related to the geography and history of the Hebrews?)
· Is it important for the debate, or for the broader issue of the relationship between science and religion, whether leading scientists are religious people?
· Can the religious beliefs of scientists affect their scientific work? Can their scientific work affect their religious beliefs?

· Does it matter, in the context of the debate, whether the Pope and other religious leaders accept the evolution model and/or other scientific theories?
· Is the term “monkey mythology of Darwin” a fair or accurate description of human evolution?
· Should there be any implications of evolution for ethics and religion? (If so, what might they be?)
· How appropriate was the author’s comparison between creationists and Holocaust deniers? What do the two groups have in common? What differences?
· What, if anything, does the Second Law of Thermodynamics predict with respect to evolution? With respect to the universe as a whole?
· Does there have to be a war between creationists and evolutionists? (See Shermer, p132.) Why might creationists perceive themselves to be at war with evolutionists? With other scientists? Why do you think evolutionists might perceive themselves to be at war with creationists?
· Is conflict between science and religion unavoidable?* (Why, or why not?) Are there alternatives to this conflict? [(*) Instructors might want to reserve this question for the suggested homework assignment below.]
· Is there a difference between how we think and what we think? (See Shermer, p136.) Shermer wanted to debate participants to “learn how to think instead of what to think.” Is this goal consistent with fields of knowledge outside of science (religion, law, medicine, business, etc.)?

Additional Material: Parts of John Polkinghorne’s *Beyond Science* (Cambridge University Press) might be appropriate additional readings related to this case. Polkinghorne addresses issues involving the relationship between science and religion that are brought out in the suggested discussion questions above (and throughout this case). Polkinghorne is a theoretical particle physicist, is ordained in the Anglican Church, and served as president of Queen’s College at Cambridge. He’s written extensively on the connections between science and Christianity and was the recipient of the 2002 Templeton Prize for Progress Toward Research of Discoveries about Spiritual Realities.

Homework 1: Assign to each discussion group either YES or NO as response to the question, “Is conflict between science and religion unavoidable?” Each group must prepare 3-5 justifications for their assigned response. Begin the next class meeting with presentations of each group’s justifications and ask the other groups to rate the justifications on a scale of 1-10 for effectiveness.

Reading 2: Assign CH10 from Shermer.

Discussion 2: Shermer’s second chapter on this debate includes several specific points from a hypothetically creationist point of view. Shermer responds to each point for the evolutionist point of view. Interestingly, not all of his responses appeal to strictly scientific arguments. Again, several leading questions are provided below for whole class discussion and/or small group discussion. With the chapter divided by Shermer’s points, another option for small group work might be to divide the list of points among the discussion groups – this option is described in the boxed section below.

· Why would a famous scientist like Darwin avoid writing about religion?
· Why is creationism an attack on all science, not just evolution?
· Are there scientific alternatives to the Big Bang model? To continental drift? To evolution?
· (Is it wrong to mutilate library books or textbooks to wipe out references to evolution or to the Big Bang?)
· (What is the status of the Bible as a historical document? What about other religiously significant texts?)
· Is there any way that the Big Bang model and evolutionary theory can be accepted alongside acceptance of Biblical accounts of creation?
· How does a fossil become a fossil, and why isn’t every being that ever lived on Earth in the fossil record?
· Evolution is said to operate on the so-called geologic time scale. Can we see evolution at work in a more obvious and direct way in the world today?
· Shermer discussed debate among scientists on strict Darwinism vs. punctuated equilibrium. (See Shermer, p141.) Over which aspects of evolutionary theory are scientists arguing? What is the desired outcome of this type of debate in science? (Why is debate welcome in science?)
· Shermer notes that historical sciences use methods of collecting data to apply to the past. Propose an experiment to test the hypothesis that mollusks (clams, snails, etc.) lived on the Earth before other types of animals.
· The argument described on pp144-145 includes the suggestion that evolution theory is to blame for “cultural and moral decline.” Please list ten items that might be causes of cultural and moral decline, and propose an experiment to test a hypothesis related to this suggestion. [Maybe also list five ways to actually quantify cultural and moral decline.]

OPTION: One option for small groups to approach this chapter might be to assign several of Shermer's numbered points to each group. Ask each group to respond to the following items for each point:

Is the author's response scientific?
What supporting information might be appropriate?
Do you agree with the author's response?
Would you characterize this response as a "warfare" response?
Can you think of an alternative response?

Homework 2: Possible assignments for homework essays:

Consider the three models of the relationship between science and religion presented: same-worlds model, separate-worlds model, and conflicting-worlds model. Give an example for each of them of a historical episode or current issue where that model was/is predominantly adopted by the participants. Write a brief paragraph for each example, describing the likely future development of a society that adopts the model wholeheartedly. Pick one of the models and elaborate on your description in several paragraphs, either as an extended essay or as a short story.

Consider the section "What is Evolution?" and the five points of Darwin's theory. For each of these points, discuss its status in the eyes of creationism, religion, science, and society. Which of these points are accepted, and which are rejected by creationists? By other religious people? By society at large? Which of these points are subjects of continuing debate within the scientific community? If any of these points were proven false, would evolution theory also be proven false?

Contrast the modes of resolution of fundamental disagreements, when these occur in science, in politics, and in religion. Give an example of each, and describe the eventual result in each case.

For an individual or for a society, it sometimes happens that we discovered that a cherished belief was based on mistaken ideas. Discuss the different ways that people react to this discovery: How does a child react? An adult? A family? A scientific community? A religious community? A democracy? A dictatorship? Yourself?

Reading 3: Assign CH11 from Shermer.

Discussion 3: Again, several leading questions are provided below for whole class discussion and/or small group discussion. The questions in the first section are discussion ideas for **Reading 3** by itself, and those in the second section are suggested summary questions to close the entire case.

<u>Reading 3</u>

· If religion is to be taught in public schools, then how should this be done? (Suggest guidelines.)
· Is separation of church and state a good thing? Is it relevant to this case?
· How should a judge's religious beliefs affect legal decisions?
· Why do people find it so difficult to accept the evolution of humans, but have no trouble "placing faith" in science in many other areas?
· How did the launch of Sputnik lead to the widespread teaching of evolution in many schools?
· Why is it so difficult for scientists to agree on a definition for science? In this case, did creation science fit the definition of science presented to the court?
· Shermer claims that creationism is not a science. (See Shermer, p167.) Please list ten ways in which creationism differs from science.
· Newton, Kepler, Pascal, and other prominent scientists might have been creationists. Assuming that this is true, is this information relevant in this case?
· Is science dogma? If not, then please describe how it might be (by its very nature) mutable, yet stable as a type of knowledge.
· Is it possible for someone to learn about other religions without changing their beliefs? Might this also apply to evolution theory (or other scientific theories)?

<u>Summary</u>

· What separates science from religion? (What makes science not religion? Religion not science?)
· Is the distinction between science and non-scientific information real and demonstrable? If not, then must this distinction be subjective and only a matter of opinion?
· (Who should decide whether our children are taught religion? What about science? Should the federal government have any say in this? State or local governments?)

· (Are there any countries in the world where religion is taught in public schools? Describe such countries in terms of type of government, freedom of expression, etc.)
· Why is it that science is taught in public schools?)
· Can a person be both a scientist and a truly religious person at the same time?
· What does science have to say about the existence of God? About life after death? Should science address these and similar issues?
· Are there any issues which science should never address or can never address? Are there any issues which religion should never address or can never address?

Homework 3: Possible assignments for homework essays:

Please consider the possible consequence for the education of our children, and for the future of our society if anti-evolution efforts discussed in this chapter were generally successful. Describe the result for our future society of: (a) teaching only evolution and not creationism, as is mostly the case today; (b) banning the teaching of evolution (and other creation-related theories such as the Big Bang model), but not teaching creationism in its place; (c) teaching creationism alongside scientific theories; and (d) teaching only creationism.

In science, it is considered a virtue, indeed a necessity, for a theory to be falsifiable – that is, able to be demonstrated incorrect. Find an example of a long-held scientific theory that was eventually shown to be incorrect. How was this done? Was the theory thereby shown to be absolutely useless? Describe the status of the falsified theory in the context of the newly acquired knowledge that falsified it. Is any religious doctrine similarly mutable?

OPTIONAL CASE EXTENSION: For more Debate Involving Science case materials, interested instructors might look at the text: Hal Hellman, *Great Feuds in Science*, New York: John Wiley & Sons, 1998. This book is a series of summaries of interesting scientific and science-related debates, organized as one chapter per debate. Of relevance to this case, Chapter 5 is titled “Darwin’s Bulldog versus Soapy Sam,” referring to public debate at Oxford University between bishop Samuel Wilberforce (“Soapy Sam”) and Thomas Huxley (“Bulldog”). The chapter presents this nineteenth century debate, and then breaks and jumps ahead to the twentieth century and the trial of John Scopes for teaching the theory of evolution in violation of Tennessee state law in 1925. Like the case study based on Shermer’s *Why People Believe Weird Things*, the *Great Feuds* book approaches the social context of knowledge, including conflict between science and law. *Great Feuds* is available on-line through Galileo as an e-book – so it can be easily added to any SCI 105 reading list. [I’ve used the chapter “Derek Freeman versus Margaret Mead” in SCI 105. –Dale]

CASE 3: DIVERGENCE IN WAYS OF KNOWING (2 TO 3 WEEKS)

Authoritative, Philosophic, and Scientific Models in Cosmogony

Background: This case study considers the history of cosmology as an example of a human endeavor that, over thousands of years, evolved into a scientific discipline. It grew from roots that lie deep in the common human experience, the need to understand our surroundings, and to predict how these will change over time. It started as the telling of stories about the origin of the earth, sky, waters, and all forms of life. Although at first it was closely allied with religion and traditional culture, it became more philosophical and abstract over the centuries. The need to explain more extensive and accurate information about our world forced cosmology to become more mathematical and dispassionate. Finally, as more advanced measuring tools were developed, and the activity of cosmology became more removed from everyday experience, it was able to distance itself from spiritual and philosophical considerations altogether, becoming one of the first true sciences…

Case Reading: This case uses only a small fraction of the material contained in these works, so unless the case is considerably extended, it would not be appropriate to require students to buy either of these books. Copies of the relevant portions might be handed out or put on reserve in the library, keeping in mind copyright law requirements. Alternately, these readings might be included in a comprehensive course pack. Other similar materials can also be substituted.

- *The World of Myth,* by David Adams Leeming, Oxford University Press, 1990 (ISBN: 0195056019)
- *The Book of the Cosmos. Imagining the Universe from Heraclitus to Hawking,* ed. Dennis Richard Danielson, Helix Books, 2000 (ISBN: 0738202479).

Suggested Instructor's References: Additional readings from *The World of Myth* and *The Book of the Cosmos* are recommended for the instructor, and possibly for the students as well, especially in an extended version of this case. In addition, useful background material on cosmology is widely available. Here are some good examples, generally proceeding from the past to the present, and from less technical to more technical works:

- *Egyptian Cosmology. The Absolute Harmony,* by Moustafa Gadalla, Bastet Publishing, 1997 (ISBN: 0965250911)
- *Mythology,* by Edith Hamilton, Back Bay Books, 1998 (ISBN: 0316341517)
- *The Greek Myths,* by Robert Graves, Penguin USA, 1993 (ISBN: 0140171991)
- *Greek Astronomy,* by Sir Thomas L. Heath, Dover Publications, 1991 (ISBN: 0486266206)
- *Conversing with the Planets. How science and Myth Invented the Cosmos,* by Anthony Aveni, Kodansha International, 1994 (ISBN: 1568360215)
- *Cosmology in Antiquity,* by M. R. Wright, Rutledge, 1995 (ISBN: 0415121833)
- *The Greek Cosmologists,* by David Furley, Cambridge University Press, 1987 (ISBN: 0521333288)
- *Astronomies and Cultures in Early Medieval Europe,* by Stephen C. McCluskey, Cambridge University Press, 1998 (ISBN: 0521583616)
- *The Copernican Revolution. Planetary Astronomy in the Development of Western Thought,* by Thomas S. Kuhn, Harvard University Press, 1957 (ISBN: 0674171039)
- *Blind Watchers of the Sky. The People and Ideas That Shaped Our View of the Universe,* by Rocky Kolb, Helix Books, 1996 (ISBN: 0201489929)
- *Cosmology and Controversy. The Historical Development of Two Theories of the Universe,* by Helge Kragh, Princeton University Press, 1996 (ISBN: 0691026238)
- *The Scientific American Book of the Cosmos,* ed. David H. Levy, Martin's Press, 2000 (ISBN: 0312254539)
- *Cosmic Dispatches. The New York Times Reports on Astronomy and Cosmology,* ed. John Noble Wilford, W. W. Norton, 2001 (ISBN: 039304937X)
- *Foundations of Modern Cosmology,* by John F. Hawley and Katherine A. Holcomb, Oxford University Press, 1998 (ISBN: 0195104978)
- *An Introduction to Cosmology,* by Jeremy Bernstein, Prentice Hall, 1998 (ISBN: 0139055487)

LEARNING OBJECTIVES

(1) To explore the relationship between religious, philosophical, and scientific knowledge.
(2) To illustrate the fruitfulness of the scientific approach in an area of knowledge that was at one time thought to lie beyond the reach of science, thus exploring the question: What is the domain of applicability of the scientific method?
(3) To see how the scientific approach was introduced over the centuries in this area of human experience. To see the practical and philosophical obstacles that impeded this process.
(4) To gain some knowledge of, and appreciation for cosmology as a science. In particular, to learn how cosmology addresses questions of fundamental importance to all human beings, not just scientists.

READING SUMMARY

The World of Myth, David Adams Leeming.

(A) Creation Stories.

(pp.15-16) "The Creation"
(pp.17-42) "The Creation Stories"

The Book of the Cosmos. Imagining the Universe from Heraclitus to Hawking, ed. Dennis Richard Danielson.

(B) Greek Philosophers

(Ch. 6, pp.37-42) "The Potency of Place," Aristotle
(Ch. 7, pp.43-45) "He Supposes the Earth to Revolve," Aristarchus and Archimedes
(Ch. 8, pp.46-49) "A Geometrical Argument," Eratosthenes

(C) Ptolemaic Universe

(Ch. 11, pp.68-74) "The Peculiar Nature of the Universe," Claudius Ptolemy
(Ch. 16, pp.92-95) "If a Man Were in the Sky and Could See the Earth Clearly," Nicole Oresme

(D) Scientific Developments

(Ch. 24, pp.145-154) "Neither Known Nor Observed by Anyone Before," Galileo Galilei
(Ch. 52, pp.317-325) "Unraveled Starlight," William Huggins

DISCUSSION QUESTIONS FOR THE READINGS

***The World of Myth*.**

The Creation

- What is a *cosmogony?* How does it differ from a *cosmology?* Do we need both?
- Why do people feel the need for a cosmogony? What needs to be explained? List several items whose origin needs an explanation.
- Is there a necessary connection between the creation of the universe and the creation of each individual person?
- Why is it that, in most creation myths, the universe was created in a perfect state? How do we reconcile that with the present state of affairs?

The Creation Stories (individually)

- Summarize the creation story.
- What are the main elements of the universe?
- What things may be created and destroyed? What things are eternal?
- Was creation planned or accidental? If planned, why? Who is responsible for creation?
- What similarities are there between this story and any of the others? How do you account for the similarities? The differences?
- What is the purpose of this creation story?

Egyptian: The Beginnings

- Why would creation stories be repeated at funerals, coronations, and other rites of passage?
- What is the role of Evil in this story? Is there one supreme deity, or more than one?
- It is not entirely clear, how mankind comes into existence. Is it a happy occasion? Speculate…

Mesopotamian: *Enuma Elish*

- How does naming something bring it into being?
- Are the gods spiritual or abstract, or they have actual physical bodies?
- Why are there successive generations of gods?
- What sorts of conflicts do we find amongst the gods? How are these resolved?
- How can the son of a god be greater than the parent?
- In what ways are the gods similar to humans?
- Why were humans created, and what was the raw material for their creation?

Hebrew: Genesis

- Why did God create the universe? Why did God create man?
- Is there anything existing, that God did not create?
- Why are there two stories about the creation of man? Wouldn't one story suffice?
- Why was man placed in the Garden of Eden? Why was he not allowed to eat the fruits of the tree of life and the tree of knowledge of good and evil?
- What would the universe be like, if man had not eaten the fruit of the tree of knowledge of good and evil? How did eating this fruit make man like a god?

- What would the universe be like, if man had eaten the fruit of the tree of life?
- How do these stories explain the current (in ancient times) state of affairs for men and women?

Indian: The *Rig Veda* and the *Brhadaranyaka Upanishad*

- If the universe emerges from nothingness, what sorts of things have to emerge?

First story:

- What does this mean: "1. Then even nothingness was not, nor existence."
- What does this mean: "4. … that which is, is kin to that which is not."
- What does this mean: "7. … he knows – or maybe even he does not know."
- Why do we find reference to things that do not exist, in a creation story?
- Why is this creation story so mysterious? What is the author trying to tell us about the nature of the universe, and our knowledge of it?

Second story:

- How is this story fundamentally different from the first?
- Is this story more or less relevant to human beings than the first?
- What is the creative principle in this story?
- How was it possible, that mortal Brahma created the immortal gods? Is there one god or many gods?

Greek: Hesiod's *Theogony*

- Why is the establishment of an organized monarchy in heaven a familiar theme of creation stories?
- Why is it necessary to have the Void come into being, "First of all…"
- How is it that the same creation process can describe the origin of deities like Earth, Ocean, and Sky as well as deities like Desire, Law, and Memory? Are these not qualitatively different?
- What is the significance of the story of Cronus' attack on Sky, his father?
- Why is the storyline repeated, as Zeus overcomes his father, Cronus?
- The deities in Greek stories are highly personified, with many human virtues and failings. Why would this kind of creation story be written, and how might this have affected Greek society?

Christian: John's Gospel

- Why is "the Word" so important in creation stories? How does it turn *chaos* into *order?* How does this relate to everyday human experience?
- What does it mean, for the Word to become flesh?

Hopi: Spider Woman

- How is it possible, that something may be created by thought? By song?
- Why is *emergence* a common feature in creation myths? How does this relate to family, and everyday human life?
- How are the powers of creation shared by the first male and female deities?
- What is the role of the Death God in this story?
- Sometimes creators make other beings by splitting themselves. How does this differ from creation out of nothing? What does this mean in everyday human experience?
- In this story many details of clan structure and family life are prescribed. Why are these included in a creation story?
- Why are we told how Turkey got dark bands in his tail feathers?
- Why are explanations of the workings of nature included in this story?
- Why is Spider Woman described in such detail, as she is about to vanish?

Boshongo (Bantu): Bumba's Creation

- Why would African blacks tell a creation story whose primary god is white? What happened to older Bantu creation stories?
- In this story creation assumes a hierarchical structure, with created beings themselves creating other beings. How does this affect the role of the gods?
- What is the significance of the story about lightning, and how fire can be drawn "out of trees?"
- Bumba, the Creator, is also described as the First Ancestor. How is he different from deities like Zeus, or Spider Woman?

Modern: The Big Bang

- Why is the brief description of the Big Bang theory in this excerpt not adequate as a scientific explanation of the origin of the universe?

- What takes the place of the gods, in the Big Bang creation story?
- Why is it important, that we can see light that emanates from the primordial fireball?
- The Big Bang theory is described as a great unifying principle. Why is this considered to have great value, in the context of present human society?
- What issues addressed by other creation stories are also addressed by the Big Bang theory? Which others are not?
- Are there some questions in cosmogony that can never be answered by a scientific explanation? By any explanation whatever?

The Creation Stories (as a whole)

- *Creation stories are a part of almost every culture:* Why is this so? What is similar about all human cultures, that they need stories like these? What are the different types of creation stories? What can we learn about the variety in human cultures, by looking at the various creation stories?
- *Creation stories explain something:* What is there that needs to be explained? Why is it not sufficient, to describe how things are at this time? (I.e., why is a cosmology not enough?) Why do we need to tell a story describing how things came to be as they are?
- *Creation stories are themselves created:* Who makes up creation stories? Is this done by the society as a whole, or by specific individuals? What drives some individuals to invent or contribute to creation stories? How are these people regarded by the other members of the society?
- *Creation stories lend authority:* What are the features of creation stories that are most relevant to the everyday life of members of the society? Does a code of conduct gain adherents more easily, if it is based on a creation story? Can creation stories be used to gain power, or justify a power structure already in place?
- *Creation stories tell us where we came from, and where we're going:* Which gods are "real" gods, and which ones are more like our ancestors? Are there characters in the stories that behave nobly, and so should be emulated? What is the fate of evil characters in the stories? In a traditional culture, where was knowledge stored, and how was it passed on to the next generation? Why should a creation story affect people's behavior?
- *Creation stories signify the value the society places upon things:* Why were some things worth creating? Does the creation god act randomly, or with a plan and foresight? Why were humans created? How do they compare to the creation god? Where do humans fit into the grand scheme of things? What is the value of the earth, the sky, the rivers and seas, the sun and the moon, and nonhuman life?

The Book of the Cosmos. Imagining the Universe from Heraclitus to Hawking.

The Potency of Place, *Aristotle.* "Aristotle's writings on physics and the heavens establish concepts that undergirded much of humankind's understanding of the world for almost two millennia."

First passage:

- What is "the potency of place"? Is this a natural concept? How does it differ from our current views about space?
- What does it mean, that "fire, earth and the like" are "elementary natural bodies?"
- Contrast the concepts or relative and absolute position.
- Why does Aristotle quote Hesiod?
- Consider the concept of place presented by Aristotle. Is this something directly accessible by the senses (i.e. *sensible*)?

Second passage:

- What concept does Aristotle take as more fundamental, space or time? How does one measure space? Time? Movement?

Third passage:

- Aristotle gives three meanings to the word "heaven." How are these related to present-day usage of this term?
- Does Aristotle consider the possibility of things existing in the universe, which are *not* sensible?

Fourth passage:

- As regards the position of the earth, what are the "facts of observation?"
- Why did the Pythagoreans believe fire to be at the center of the universe?
- Where is the "center of the animal?"
- What kinds of arguments does Aristotle use to rebuke others' arguments about the shape and size of the earth?

Fifth passage:

- How is it different, for the earth *to be* the center of the universe, or for the earth *to be placed at* the center of the universe?
- Aristotle explains why objects move toward the center of the earth, why the earth itself does not move, and why the earth is spherical. What parts of his argument are based on observation, and what parts reflect his personal philosophical bias?

Sixth passage:

- Aristotle concludes that the earth "is not of great size." Are his arguments all equally valid? How did he get the information that he uses to support his conclusion?
- Put yourself in the position of a common person in Aristotle's time, how would you react to this statement?

The article as a whole:

- Aristotle's approach to cosmology is very different to that of the stories of traditional cultures. How?
- Aristotle seems to support all his statements with rational arguments based on observation and logic. Is this really the case?
- Are all of Aristotle's observations actually things he saw himself, or had first-hand reports about?
- What are the fundamental philosophical assumptions, about the natural world, that Aristotle relies upon implicitly?

He Supposes the Earth to Revolve, *Aristarchus and Archimedes.* "A great ancient mathematician tells of the strange theory of Aristarchus, according to which the sun, not the earth, stands at the center of the universe."

First passage:

- Many ancient people believed the earth was round, not flat, and that the sun was at the center of the universe, not the earth. Nevertheless, the common myth is that these things were only discovered around the seventeenth century. Why?
- Why would anybody want to think about the question, how many grains of sand the universe might hold? Is there any practical reason to pursue this question? Is there a correct answer? A verifiably correct answer?
- How can the definition of the term *universe* be an issue? Isn't it obvious what this means?
- How might Aristarchus' hypotheses lead to the conclusion, that the universe is larger than previously thought? Is the assumed motion of the earth relevant?

Second passage:

- The Aristarchan theory entailed a huge increase in the size of the universe. How big is the universe? Can we ever know for sure?
- Why is it important to have numbers that are so big, that they describe the number of grains of sand it would take to fill the universe?

The article as a whole:

- Archimedes was led to develop new mathematical tools by his "scientific" considerations about the nature of the universe as a whole (i.e. cosmology). Why does this happen in a scientific inquiry, but not in other types of investigations of the same phenomena?
- Are there other instances when this occurred, or is this an isolated event?
- Of what use are such huge numbers?
- The two hypotheses, namely that the earth either does or does not move, were equally plausible, given the information available to the ancients. Could they nevertheless, somehow have known which one was right?
- If one cannot choose between two contrary hypotheses based on observation, can there be other criteria for making a choice? Is it possible, that one of these assumptions was more scientifically fruitful? Should one or must one make a choice at all?
- The number 10^{63} is very large, but how large is it? For example, how big would a container have to be, to hold this many air molecules under ordinary conditions? How big would the universe have to be, to hold this many galaxies? How small would angels have to be, for a pinhead to hold this many? If a PC running at 1GHz (i.e. 10^9 binary calculations per second) needed to make this many binary calculations, how long would it take to finish?

A Geometrical Argument, *Eratosthenes.* "'To measure the earth' defines geometry, and indeed Eratosthenes shows how to calculate the size of the whole earth."

- What is the difference between a *gnomon* and a *sundial?* How is a sundial able to measure time of day, whereas a gnomon cannot?
- How would the ancients measure the distance between Aswan and Alexandria? How would they know that Aswan was almost exactly due south of Alexandria?
- Describe a procedure for obtaining a "ballpark estimate" of some physical quantity that you could not in practice measure directly.
- Suppose you were a common person in ancient times, and you were told that Eratosthenes had measured the size of the earth. Would you believe it? If the procedure were explained in detail to you, would you change your mind?
- If Eratosthenes' procedure was not an actual measurement of the size of the earth, what use was it? Can you describe a procedure for making a *true* measurement of the size of the earth?

The Peculiar Nature of the Universe, *Claudius Ptolemy.* "The most influential astronomy textbook of all time smashes some enduring cliches about geocentrism."

The heavens move like a sphere:

- Ptolemy claims the heavens are spherical. What basic set of observations motivates this description? Are these observations accessible to the common person?
- In what two distinct ways does the spherical hypothesis bring unity to the account of observations of the heavens?
- Why is it important, for one description of the heavens to simultaneously explain the observations of people located at different times? At different locations?
- Why is it ridiculous, "that the same stars are already ignited or extinguished for some observers while they are not yet for others?"
- Why is it "utterly obvious that the very same stars that rise and set in certain regions of the earth neither rise nor set in other regions?" How does Ptolemy know this?

The earth too, taken as a whole, is sensibly spherical:

- In his arguments for a spherical earth, Ptolemy uses the timing of rising and setting of stars, and lunar eclipses. What exact information is he referring to, and how might he have gotten it?
- What does the reader have to do, in order to follow Ptolemy's geometrical arguments? Are his arguments rigorous? Are they obvious, or do they require a certain level of intelligence on the reader's part?
- To seal his argument, Ptolemy invokes the image of a mountain seen from a sailing vessel, as it rises out of the sea. Why is this useful?

The earth has the ratio of a point to the heavens:

- Does Ptolemy know how big the heavens are? The earth?
- Once again Ptolemy wants to unify the accounts of all observations. How does the earth's having the "ratio of a point to the heavens" accomplish this unification? What would happen if the earth was not like a point, compared to the heavens?

Neither does the earth have any motion from place to place:

- Why was it so difficult for Ptolemy to accept that the earth might be moving?
- In light of the arguments in the previous section, what is the obvious flaw in Ptolemy's argument, that the earth is immobile?
- What does Ptolemy mean by "proper, natural motion?" Is this concept based on observation? Does it have explanatory and predictive power?
- How does the uniqueness of the universe limit any scientific study of it? Are there other areas of study, scientific or otherwise, that have this "problem?" Is cosmology a science?
- Does the concept of proper and natural motion be applied to the earth?
- At the same time Ptolemy describes the earth as having very little mass, and as having great mass. Why does he do this? Does it make sense as part of the logical argument for earth's immobility?
- Ptolemy is reluctant to accept the idea that the earth might be rotating. Are his arguments based solely on common sense and observation, or does he show a theoretical bias? What concepts does he lack, that would make this possibility more plausible?

The article as a whole:

- What kind of arguments does Ptolemy use to prove his case? Are they abstract and philosophical, or are they based on observation? Are they persuasive to the common person?
- How does Ptolemy deal with competing hypotheses? Does he refute them in a logical way, by using reasoning and observations; or does he dismiss them out of hand?
- Why did Ptolemy's work endure for so many centuries, considered as "The Greatest" contribution in the area of astronomy and cosmology? Were competing works available in this area, contradicting his conclusions? When and why did Ptolemy fall out of favor?

If a Man Were in the Sky and Could See the Earth Clearly, *Nicole Oresme.* "A medieval churchman, astronomer, and minister of finance considers the 'economical' idea that the earth rather than the rest of the universe rotates every twenty-four hours."

- What does the term *relativity* mean, in the most general sense? How is it related to *subjectivity* and *objectivity?*
- Before putting his own arguments forward, Oresme presents the arguments of those with opposing views. Why does he do this? Wouldn't this undermine his own arguments? Is it customary to this in science? Outside of science?
- Oresme argues for relativity of motion in the context of a moving ship. Why does he not just make abstract or philosophical arguments? Why use a ship as his example, rather than some other moving object?

- As part of his argument that the earth may as well be moving, Oresme asks the reader to imagine two hypothetical situations involving the motion of the earth and the heavens. How does relativity play a role in the argument?
- According to Oresme, "anybody with good sense" may easily imagine that they see the earth rotating below, from the vantage point of the sky. How might a common person be affected by this "experience?"
- Oresme again puts forward a ship as a model for the earth, to show that the air could move along with the earth, without causing great winds for those on its surface. How might this change a person's conception of the earth as a whole? I.e., if the earth is like a ship, then what else might we conclude about the earth?
- If you shot an arrow straight up from a swiftly moving ship, would it come straight back down to the same spot? How do you know?
- Oresme refers to Aristotle as an authority several times, even though Aristotle had been dead for seventeen hundred years. Why was he still considered to be a legitimate source of knowledge, and a valid foundation for rational arguments? What did Aristotle do, that was so enduring?
- Does Oresme actually believe that the earth rotates, not the heavens? Does it matter?

Neither Known Nor Observed by Anyone Before, *Galileo Galilei.* "An ambitious professor inaugurates the age of the telescope by telling how he discovered the true face of the moon, the moons of Jupiter, and the secrets of the Milky Way."

First passage:

- Why was Galileo so excited about the newly invented telescope?
- Why does it matter, how many stars there are in the sky?
- Why does it matter, that the surface of the moon is not smooth but rough, "just like the surface of the earth itself?"
- Why does it matter, the nature of the Milky Way, or of "nebulous" stars?

Second passage:

- Why does Galileo describe how he constructed his telescopes?
- Put yourself in the place of a common man in Galileo's time. What might be some of the "great advantages" the telescope would provide? Why did Galileo, instead, turn his telescope to the heavens?
- Galileo describes the moon's dark and bright areas as they appear under the changing illumination of the sun. He interprets the observations by analogy with the effect of the sun on valleys and mountains on the earth. If the moon is in the heavens, why is this a legitimate analysis?

Third passage:

- Why does Galileo describe in detail the explanation of the moon's phases, as seen from the earth?
- Why was it a novel concept, that the moon is itself illuminated by the earth? What does this suggest about the relationship of the earth and the moon? The earth and the heavens?

Fourth passage:

- Why is it important to classify stars in terms of stellar magnitude? How has the interpretation of this measure changed from ancient to modern times?
- The apparent sizes of stars are not magnified as much by the telescope, as the apparent sizes of the moon and nearby objects are magnified. Why does this necessitate an explanation from Galileo?
- In ancient times, all stars were assumed to be the same distance from the earth. What indicates to Galileo that this is may not be so?
- What is the modern term for "nebulous" stars? Was Galileo correct in his understanding of these?

Fifth passage:

- How did Galileo know that the small stars he saw near Jupiter were not ordinary stars?
- Why did Galileo describe his observations of the four moons of Jupiter in such detail? Why did he name them "the Medicean stars?"
- What is the fundamental significance of the discovery by Galileo of the moons of Jupiter?

Sixth passage:

- Why did people find it so impossible, to imagine that two objects might revolve around each other, and at the same time orbit the sun? How does Galileo fix this problem?
- In what sense was Newton's work "prepared and defined by Galileo?"

The article as a whole:

- Some people in Galileo's time, in particular the Pope, found his work threatening to their worldview. Why? Was Galileo a religious man? Did his work contradict sacred scripture?
- Consider the kinds of arguments Galileo uses to interpret his observations of the moon and other heavenly bodies. How did he view the relationship between the earth and the heavens?
- Galileo was very excited about his discoveries, but these were eventually the source of a great deal of trouble for him. He was eventually forced to recant his support for the Copernican heliocentric theory, and ended his life

under house arrest, forbidden to teach that the earth revolves around the sun. Do you think he was surprised by this? Should he have been? Can you think of something analogous that might happen today?

Unraveled Starlight, *William Huggins.* “The first person to analyze starlight using a spectroscope recounts the moment when he solved the riddle of the nebulae.”

Comte passages:

- What were some of the “theological and metaphysical influence(s)” on astronomical science to which Comte refers?
- How might Comte react to the idea, that we might someday send people to the moon, or to Mars?
- What does Comte think we may know about stars? Why does he differentiate between scientific investigation of stars, and of the sun and planets? Can you think of a similar division in present day science?

First Huggins passage:

- Helium is present in the earth’s atmosphere, but it was first discovered as existing in the sun. Why didn’t we know about it before that?
- Spectroscopy relies on the assumption that elements and compounds emit and absorb light in the same way, on the earth and in the heavens. How is this assumption justified?

Second Huggins passage:

- What was similar about Huggins’ and Galileo’s experiences?
- Why was Huggins so excited about the new method of observation?

Third Huggins passage:

- Why did Huggins use solar light reflected from the moon as a test of his apparatus?
- Great discoveries followed “almost every night,” as the astronomical observatory “began for the first time to take on the appearance of a laboratory.” Why is this significant?

Fourth Huggins passage:

- What does it matter, whether some nebulae are made of gas, or all are collections of stars?
- The existence of gaseous nebula allows Huggins to speculate on how the solar system may have been formed. Where is the distinction now (i.e. in Huggins mind), between earthly phenomena and the heavens?

Fifth Huggins passage:

- How does one see motion of the stars across the line of sight?
- Why is it much more difficult to see motion in the line of sight? How did Huggins solve this problem?
- Why would anybody want to know, how the stars move in detail? Aren’t they supposed to be “fixed” stars?
- What two scientific principles or methods were combined to measure the motion of stars in the line of sight? Why was it necessary “to construct a spectroscope of greater power for this research?”
- Why is it that well known, experienced astronomers were slow to take up the new techniques developed by Huggins?

The article as a whole:

- In what sense did Huggins *unravel* starlight?
- Does it seem reasonable or likely, that by making measurements in a laboratory on earth, we can really learn about the chemical composition of a distant star? About the star’s motion? Is vision in some fundamental way different from other senses? Are there some things that one could never learn from a distance?
- When Galileo made his discoveries about the cosmos, he got into big trouble. Nothing like that happened to Huggins, or to any of his colleagues. How had society changed from the seventeenth to the nineteenth centuries? How had science changed?
- Describe the limits of astronomical or cosmological scientific research in Huggins’ time, and contrast these to the limits in Galileo’s time, and in Ptolemy’s time. What are the limits today? Are there some ultimate limits to this type of research that will not or should not ever be exceeded?

CASE PLAN

[Coming soon!]

CASE 4: WHY DO WE THINK THAT THE UNIVERSE IS EXPANDING? (1½ TO 2 WEEKS)
Edwin Hubble's Beautiful Cosmology

Background: Scientists are often faced with the challenge of comparing data (collected from selected observations, or experiments) against a set of competing models. Edwin Hubble faced that challenge, and his resolution was not as cut-and-dry as we might have imagined from an overly simplistic notion of "scientific method." This case should require students to identify the major structural points of three cosmological models, and then to reconcile themselves with Hubble's interpretation of data based, in part, on aesthetic criteria.

Reading 1: Norriss S. Hetherington, "Hubble's Cosmology," *American Scientist*, **1990**, *78*, 142-151.
Reading 2: James W. McAllister, "Is Beauty a Sign of Truth in Scientific Theories?" *American Scientist*, **1998**, *86*, 174-183.

[**Suggested Instructors' References:** SCI 105 instructors might refer to James Trefil and Robert M. Hazen's *The Sciences: An Integrated Approach, 2nd Edition*, New York: John Wiley & Sons, 1998, CH15 "Cosmology" for some background information on cosmology and on Edwin Hubble's contributions. One of the articles from the CASE 3 Readings might also be appropriate background: William Huggins' "Unraveled Starlight" in *The Book of the Cosmos. Imagining the Universe from Heraclitus to Hawking*, Dennis Richard Danielson, Ed., Helix Books, 2000, pp 317-325.]

<u>Learning Objectives</u>
(1) Examine the comparison of data with scientific model(s).
(2) Dispel notions about overly simplistic models of a "scientific method."
(3) Consider the proposition of and the competition between scientific models.
(4) Define scientific aesthetics and appreciate the value of aesthetic components in scientific models.

OUTLINE FOR READING 1

Phase I: Existence of "Island Universes"
Competing models - a) Spiral nebulae are nearby objects, within the Milky Way.
b) SN are distant, beyond the edges of the MW.
Tools - a) Measurements of radial and internal velocities of SN.
b) Period-luminosity relation of Cepheid variable stars.
Protagonists - Hubble, van Maanen, Shapley
Others - Slipher, Humason; Leavitt, Ritchey, Duncan, Russell, Seres, Nicholson

Phase II: Apparent Velocity-Distance Relation
Inspirational model - deSitter (relativistic) static model.
Protagonists - Hubble, deSitter, Silberstein, Stromberg & Lundmark
Others - Slipher, Humason

Phase III: Expanding Universe
Competing models - a) Lemaitre's relativistic non-static model.
b) Milne's non-relativistic random motion model.
c) Tired-light model of Zwicky.
Hubble's guiding principles - a) General Relativity Theory.
b) The Cosmological Principle.
Protagonists - Hubble, Lemaitre, Milne, Zwicky
Others - deSitter, Eddington, Tolman, Mayall, Shapley, Einstein, Baade; Robertson, Minkowski, Humason; Mrs. Hubble

Overall: The Birth of Modern Cosmology
Tools: Huge telescopes, astronomical photography, Cepheid variable stars
Protagonists: Hubble, van Maanen, Shapley; and various theorists
Conclusion: The universe is bigger than we thought, and it's getting bigger all the time! Also, Einstein's GRT rules...

CASE PLAN

Assigning Reading 1: The first reading might be assigned with some brief overview of the contents: The article describes (in part) Edwin Hubble's contributions to the science of cosmology within the context of his scientific contemporaries. Students might be advised to approach the article initially by focusing on the people described or noted in the article.

Discussion 1: Following the first reading of "Hubble's Cosmology," students should be prepared to identify and characterize the scientists (and others) noted in the article. Certain stakeholders will be especially important – these are the proponents of the various cosmological models presented in the paper. (The models themselves will be discussed later.) It might be appropriate to ask students to prepare a short dialogue, or skit, to illustrate the relationship between Hubble and one (or more) of the other people noted in the article.

Re-assigning Reading 1: The second reading assignment should revisit "Hubble's Cosmology," but with the focus shifted to the scientific models themselves. Hopefully, the students have identified the stakeholders (proponents). This should help them to locate the models in the article. However, it will likely require some prompting and additional discussion to help them to describe the models in any meaningful way.

Discussion 2: Ask the discussion groups to prepare visual representations of the cosmological models described in the article. These simple diagrams need only convey the important aspects of these models, and it should be clear from the diagrams how the models differ from one another. (It might be appropriate to separate the article into Phases as identified in the Outline above. Through preliminary discussion, the students might recognize these divisions themselves.)

Discussion 3: How did Hubble choose between competing models? What role did direct comparison between data (empirical finding) and theory (models) play in his choice? Did he (in fact) choose between them? Please characterize the role adopted by Hubble with respect to presentation of his empirical findings and their interpretation in terms of the competing cosmological models. (What was Hubble's agenda?)

OUTLINE FOR READING 2

[It is worth noting that McAllister, the author, is a philosopher and not a scientist.] McAllister begins with some reasons for attempting to judge scientific theories without testing them empirically and notes that the beauty of the theory is a tempting alternate criterion, namely, the more beautiful a theory is, the more likely it is to be an accurate representation of reality. Several advocates of this view are mentioned, including P. A. M. Dirac and Steven Weinberg, with quotes from most.

Next, a number of variations of this test, based on the particular type of beauty that a theory might possess, are considered. In each case, McAllister concludes that the proposed test cannot work. In order to explain why so many prominent scientists have relied upon beauty as a sign of truth, he introduces his own theory: "Scientists are engaged … unconsciously … in a systematic inductive search for aesthetic properties of theories that constitute a sign of truth." In other words, scientists' judgments of the beauty of scientific theories are modified over time so that they consider to be beautiful the aesthetic properties of the most successful theories. McAllister's theory would suggest that an innovative theory would be likely to be viewed as ugly when first introduced but, as experimental evidence in favor of the new theory is gathered, more and more scientists would think it is beautiful. Several examples of this shift in perception are mentioned, including Newton's suggestion that gravity acts instantaneously over distance.

As an analogy to the way that scientists change their views of what makes a theory beautiful, McAllister considers the evolution the standards for mate selection in some species such as the peafowl. He then goes on to use his theory to provide an explanation of the nature scientific revolutions distinct from Thomas Kuhn's. McAllister next shows that his theory of changing perceptions of beauty can be applied to disciplines outside of science such as architecture.

While there is little evidence that beauty is a useful indicator of the truth of a scientific theory, McAllister does not categorically deny that possibility. The article ends with a discussion of the merits and deficits of two extreme possibilities for the way scientists judge theories: relying heavily on considerations of the theory's beauty and completely ignoring them.

Assigning Reading 2: Ask students to read "Is Beauty…" while keeping the Hubble case in mind.

Discussion 4: What is beauty? (Each discussion group might assemble a criteria list.) What is scientific beauty? (Again, each group might prepare a list.) Ask the students to distinguish between two figures (one showing a symmetric structure, one showing a similar, but non-symmetric structure) and to discuss this distinction within the context of their criteria for scientific beauty. From their identification of "symmetry" as a key scientific aesthetic value, return to Hubble's consideration of the competing models, and ask the students to re-evaluate their ideas about choosing between competing scientific models.

Additional Discussion Questions: *What is the inductive method?* Philosophers have described a variety of approaches to understanding the concept of truth, among them the correspondence theory of truth (a statement is true if what it claims corresponds to reality), the coherence theory of truth (a statement is true if it coheres with other true statements – different versions of this approach provide different explanations for what is means for statements to cohere), and the pragmatic theory of truth (a statement is true if it is useful). [I'm not a philosopher, so you should take these explanations with a large grain of salt.] Which approach do scientists take? Which approach does McAllister take?

Related Mini-Case: This case requires students to consider the form and function of scientific models. The Childbed Fever mini-case (from Elaine Butler) on the SCI program faculty web page (http://sci.mercer.edu/faculty/fac.htm) addresses model construction through an exploratory exercise and might be used elaborate on their origins.

CASE 5: ORGANIC SOUP? (1 TO 2 WEEKS)
Chemical Origins of Life

Background: While evolution theory (approached in CASE 2 and in CASE 6 in this set) might be described as a scientific model for the origins of species, a more basic question might be, "What scientific models describe the origins of life itself?" While the answers to this question constitute a long list, chemist Stanley Miller started researching models for the chemical origins of life his first days in graduate school. This case represents an introduction to the questions involved with experimental design, and it uses as examples Miller's seminal experiments on modeling pre-biotic (before life on Earth) chemistry.

Reading 1: Stanley L. Miller, "A Production of Amino Acids Under Possible Primitive Earth Conditions," *Science*, **1953**, *117*, 528-529.
Reading 2: Selected sections from Stanley L. Miller, "Production of Some Organic Compounds Under Possible Primitive Earth Conditions," *Journal of the American Chemical Society*, **1955**, *77*, 2351-2361.

LEARNING OBJECTIVES

(1) Begin survey of experimental design with the simplest form of controlled experiment, a laboratory recreation.
(2) Look at diagnostic techniques by indirect observations (in this case, chromatography). While macroscopic (large, or obviously visible) subjects might be identified by direct observation (for example, identifying a species of plant by its physical characteristics), molecules (individually nanoscopic, or very small) must typically be identified by comparative observations of their properties. Most chemicals simply cannot be identified by sight alone.
(3) Familiarize students with the parts and organization of a primary research paper. (As represented by **Reading 2**.)
(4) Follow up on previous discussions on ways of knowing and tests of consistency by examining how Miller's results fill a hole between the historical scientific model of the pre-biotic Earth and nascent models for the origins of life.

OUTLINE FOR READING 1

Hypothesis: Organic compounds formed in the primordial Earth atmosphere.
Experiment: Miller's apparatus circulated gases (H_2, H_2O, NH_3, CH_4) through electrical discharge over period of several days.
Obvious Results: Formation of colored (organic) residue inside the vessel.
Interpretation: Miller used paper chromatography to separate and identify the materials in the residue. Chromatographic (separatory) properties of these materials matched the properties of known samples of several amino acids. Miller specifically identified five amino acids.

OUTLINE FOR READING 2

Abstract: A mixture of H_2, H_2O, NH_3, and CH_4 was subjected to electrical discharge for a period of one week. Six amino acids were identified in the chemical reaction products, along with CO, CO_2, N_2, and some incompletely analyzed materials associated with metals and polymers.
Introduction: The pre-biotic Earth was believed to have had a chemically reducing atmosphere, and no laboratory recreations had been made (to-date) to demonstrate the formation of organic molecules in that atmosphere following electrical discharge (essentially lightning).
Methods: Three different apparatus configurations were tested. The organic materials formed were analyzed by chromatography and compared to known samples of several amino acids.
Results: Control experiments verified that the electrical discharge was required to form the amino acids and that microbes didn't significantly contribute to the formation of organic material during the experiments. Miller identified six amino acids produced under his model pre-biotic Earth conditions.
Discussion: Miller indicates that the results' significance for a theory of origins of life is based only on speculation. However, he appeals to a sense of consistency. Organic compounds are formed in reducing environments and decompose in oxidizing environments. His experiments showed how readily amino acids form from simple starting materials. Therefore, it's consistent to suppose that large amounts of organic materials formed in the pre-biotic atmosphere to provide the raw materials for life.

CASE PLAN

Assigning Reading 1: In 1952, Stanley Miller was twenty-two years old and in his first year of graduate school at the University of Chicago. He had just started working under mentor Harold Urey, a chemist specializing in primitive Earth chemistry. On his own, Miller initiated an unusual experiment: He filled a glass vessel with several gases, and then introduced an electrical discharge. Subsequently, Miller submitted a brief description of his experiment and results to the journal *Science* without sharing authorship of this report with his research mentor. (Urey was acknowledged in a footnote.) The first reading assignment for this case is the brief report from *Science* – it's very short, so students should be expected read it extremely thoroughly and come to class prepared to discuss the contents.

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Discussion 1: Discuss background on experiment itself. The point here is to make sure that the students understand the point of Miller's experiments. Possible leads include:

1. *Describe the primitive Earth atmosphere model upon which Miller based his experiment.*

The atmosphere was believed to contain hydrogen gas (H_2), water vapor (H_2O), ammonia (NH_3), and methane (CH_4). This combination of chemicals was described as a reducing atmosphere. (A follow up question is **5** below.)

2. *Hypothesize about the likely state of the Earth's surface immediately following the formation of the planet.*

The primordial Earth was probably fairly warm. The surface of the Earth might have been covered with rapidly cooling molten rock, from which gases continued to escape. As the temperature cooled, water would have condensed (to liquid) and covered (at least partially) the Earth.

3. *Are their any locations on the current surface of the Earth that might resemble your description above?*

Volcanoes

4. *How do you think that scientists might have arrived at the primitive Earth atmosphere model upon which Miller based his experiment?*

They analyzed the gases escaping contemporary active volcanoes. We hypothesize that the primordial Earth atmosphere was primarily constituted of gases produced from similar chemical processes as those producing the contemporary volcanic gases.

5. *Distinguish between reducing and oxidizing (with respect to chemical environments). Consider (specifically) the element carbon and its most likely form in each type of environment.*

Depending upon the chemistry background of the students, this question might require more instructor prompting. The contemporary atmosphere contains a significant amount of oxygen gas (O_2). As a result, exposed materials tend to react with that oxygen to form oxygen-containing materials (oxides) – we have an oxidizing atmosphere. For carbon, the ultimate fate in oxidizing conditions is carbon dioxide (CO_2). (Some students may have heard that CO_2 is a greenhouse gas accumulating in our atmosphere, so they're familiar with the notion of CO_2 as the natural gaseous form of carbon today.)

The primitive atmosphere model, however, features no oxygen gas. Instead, we believe that it contained hydrogen gas (H_2) and hydrogen-containing materials (like methane and ammonia). An environment in which an element is likely to combine with hydrogen is called reducing (in contrast with oxidizing, above). Organic molecules contain (by definition) carbon and hydrogen, and so we expect that would only naturally form under reducing conditions. This was the guiding question that motivated Miller to perform his experiment. (What organic molecules will naturally form in an environment of volcanic gases?)

6. Miller concluded that several amino acids formed under the experimental conditions that he chose. What are amino acids? The title of this case study is "Organic Soup?" – this suggests an appropriate follow up question: What is Organic Soup?

Simply, "amino acid" is one type of organic molecule. All amino acids contain two so-called functional groups: (a) A nitrogen atom connected to two hydrogen atoms, and (b) a carbon atom connected to two oxygen atoms. The actual chemical structures of amino acids aren't necessarily important to further discussions in this case study. However, if some exposure to chemical modeling is desirable (especially if the course plan includes the extended case on *The Double Helix*), then a hands-on exercise with chemical models might be inserted here.*

Most importantly for the Origins case set theme, amino acids are the building blocks of the biological molecules called proteins. Proteins are assembled by connecting different amino acids in very specific sequences, yielding a net molecular structure to match a biochemical function. If we have verifiable information that amino acids could have readily formed on pre-biotic (lifeless) Earth through normal chemical processes, then we have collaborating information to support hypotheses proposing that life arose on Earth within organic soups – areas where the pre-biotic organic materials (like amino acids formed in Miller's experiment) were concentrated. (It's been suggested that organic materials might have become concentrated in tidal pools and/or in oil slicks formed from other naturally pre-biologically produced organic materials.)

*Instructors might insert the molecular modeling sub-case here. (A brief description follows this Case Plan.)

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Discussion 2: Discuss experimental control. This is the first approach to experimental design (in the Origins case set). The point here is to lead the students toward understanding how scientists choose observations that will allow them to obtain some verifiable information. Possible leads include:

1. *What advantages do laboratory recreations provide as the subjects of scientific observations?*

Choose conditions. *Follow up question: Which conditions did Miller choose? What other possible conditions might be chosen? How are these conditions characterized (measured)?*

> Examples of conditions include: Temperature (measured in degrees); total pressure inside the vessel (measured in centimeters of mercury as with a mercury-containing manometer); composition of the mixture of materials inside the vessel (measured in milliliters and centimeters of mercury); re-circulation rate (possibly measured in milliliters per hour); total time for the experiment (measured in hours); magnitude of the electrical potential providing the electrical discharge (measured in volts); composition of the vessel; and composition of the electrodes.

Limit variability. *Follow up question: What possible variations on Miller's experiment might be useful to observe?*

> An infinite number of possible experimental variations exists for any of the conditions listed above. It might be appropriate to discuss which variations might provide additional useful information.

2. *In science, it is often useful to distinguish the collection of materials under investigation as a single set (separated from the surroundings) – this is the system. What constitutes the system in Miller's experiment?*

Circulating fluids – Initially water, hydrogen, ammonia, and methane, the circulating fluids also contained other materials by the end of the experiment, including several amino acids, colloidal silica, and other unidentified organic materials.

Inner surface of the vessel – Throughout the experiment, the circulating fluids were in contact with the inner surface of the vessel. The vessel is glass (SiO_2). Miller noted that some decay of this surface occurred during the experiment to produce colloidal silica (very small particles of SiO_2 suspended in the water). This indicated that the glass vessel was not completely chemically inert throughout these experiments (as might have been expected).

Electrodes and electrical discharge – Miller didn't indicate the composition of the electrodes in this paper. Presumably, they were metal. (In the second paper, he indicated that he used tungsten electrodes.) As with the inner surface of the vessel, there was some assumption that the electrodes were chemically inert. Miller proposed that the electrical discharge itself was the agent driving the formation of new materials in this experiment.

Aside: In a famous electrochemical experiment, Barnett Rosenberg studied the effects of electricity on bacterial growth. He (and his co-workers) observed that under the experimental conditions, cell growth was stopped. However, upon further investigation, they found that it wasn't the electricity that stopped the cell division, but rather was a platinum-containing material that was formed from the platinum electrodes that he used in his apparatus. This material turned out to be the chemical *cis*-platin, used today as an anti-cancer agent.

Other possibilities – Other possible components of the system include impurities in any of the chemicals that Miller introduced and/or biological contamination. Miller addressed the issue of biological contamination in both papers.

3. *Based on your previous answer(s), please propose some additional experiments to verify that the mechanism for the formation of amino acids was indeed the introduction of an electrical discharge to Miller's chosen mixture of simple materials. (What other possible agents might have caused the formation of organic materials in this experiment?)*

Here, the point is that the students must consider appropriate control experiments to verify the conclusion that the electrical discharge led to the formation of the amino acids Miller identified in the organic residue. What if the amino acids were formed by heat generated by the electrical resistance across the electrodes? What if the amino acids were formed by reactions involving the colloidal silica (not necessarily requiring electricity at all)? Working from the starting point of some "what if" scenario, each discussion group should be able to propose one or more additional experiments to increase their certainty that Miller's interpretation of his results was the <u>only</u> possible interpretation.

4. *Miller identified five amino acids in the organic residue produced in his experiment. In as much detail as possible, please attempt to describe how he made those identifications.*

Drawing on the context (very little) provided in the paper and on their previous science education, the students will hopefully construct some notion of the technique of diagnostic chromatography. Chemicals can be identified based on their separatory properties. In this particular experiment, Miller used a two-dimensional paper chromatography experiment. First, had applied his sample to the corner of a piece of chromatographic paper and allowed a solvent to rise up the paper and separate the sample components. Then, he turned the paper 90° and allowed a different solvent to further the separation process. The coordinates of a sample component (on the paper) should therefore have some correspondence with that component's identity. The chromatography demonstration activity below provides a follow up to this question – a chance to see a live chromatographic separation.

CHROMATOGRAPHY DEMONSTRATION

Distribute chromatography demonstration kits to the discussion groups. Each kit contains:

- Three black markers
- Chromatography paper
- Disposable sample cups
- Small jar of water
- Small jar of isopropanol (rubbing alcohol)
- Small jar of acetone (nail polish remover)

Students' Objective: The instructor should use one of the markers from a chromatography kit to mark on a piece of paper ("unknown"), then divide the marked paper into samples – one per discussion group. The groups will then use diagnostic chromatography to identify the marker used.

Students' Protocol: This set of step-by-step instructions can be provided to the students, or reviewed by the instructor prior to initiating the activity.

1. Cut twelve strips of chromatography paper, approximately ½" in width by 2½" in length.

2. At one (and only one) end of each strip, draw a line **with a pencil** across the width and approximately ½" from the end.

3. Divide the paper strips into four sets of three.

4. For one set, draw a line over the pencil line with one of the markers. Do this on each strip. Repeat this procedure for each of the other two markers on two other sets of paper strips. (Consider labeling the strips, so that you can keep track of which strips represent which marker.)

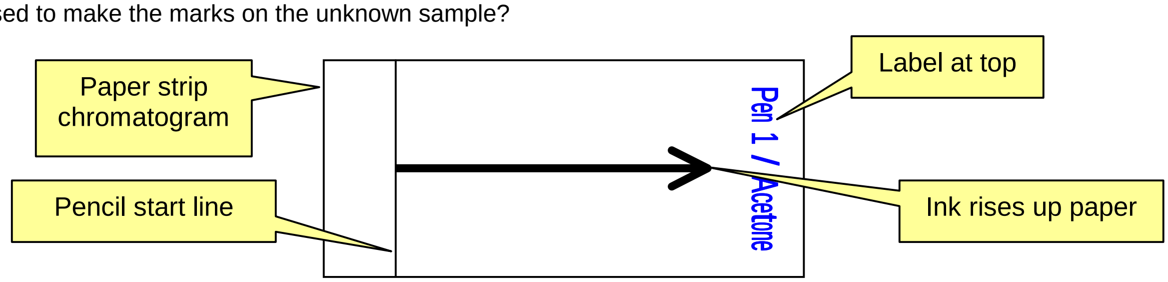
5. For the fourth set of chromatography papers, you will blot ink from the unknown marked paper onto the pencil line. Do this by moistening the ink with the available liquids (water, isopropanol, and acetone), and then dab the wet sample over the pencil line. (You want to transfer as much ink as possible to the pencil lines.)

6. Put water into four disposable cups to a depth of ¼". Repeat for isopropanol and acetone. (Consider labeling the cups, so that can keep track of which liquid is which.)

7. Divide the paper strips (with ink samples) between the cups of liquids. Insert the strips into the cups so that the pencil and ink lines on each are just above the surface of the liquids in the cups.

8. Leave the paper strips in the cups as the liquids rise up the papers. You should be able to observe some movement of inks along the strips accompanying the rising liquids. After the liquids have risen nearly to the top of the papers (look for the liquid front, not the inks), remove the papers from the cups. While each paper is still wet, draw a pencil line across the width of the strip at the level to which the liquid rose on that paper.

9. Compare the papers of the sample markers with the papers from the unknown ink sample. Which marker was used to make the marks on the unknown sample?



Assigning Reading 2: The *Journal of the American Chemical Society* article is significantly longer and more technically intensive than the brief *Science* report. Miller's further experiments elaborated on the trial experiment that he had reported on previously. This second reading represents the typical format for a report in the primary scientific literature.

It is suggested that the reading assignment include cursory review of all the sections of the article. However, students need only read the following sections: Abstract (not labeled, need to direct students to the paragraph beneath the title), Introduction, Construction of Apparatus, the first two paragraphs of Synthesis of Compounds Identified, Discussion, and also examination of Figure 8 (paper chromatography of the amino acids).

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Discussion 3: Discuss the general issue of the contents and format of a primary research paper, then discuss the specifics of Miller's experimental designs and interpretation of results.

1. *Please consider Miller's paper from the Journal of the American Chemical Society, and propose a list of the basic parts included in a primary research paper.*

At the bare minimum, we'd like to identify **introduction**, **methods**, **results**, and **discussion**. In this paper, Introduction and Discussion are separate and labeled sections, while the methods and results for several experiments are combined together by experiment under descriptive headings throughout the paper body. Another common combination of these basic parts (especially in more contemporary chemical literature) is Results & Discussion, again under descriptive headings by experiment. Other paper parts to note: Abstract, references, author's address, figures, and data tables. Each of these supplementary items is also important, and might be appropriate entries on a student list of primary research report components. Ask the students to determine the purpose of each section. *What information is in each section and why is it necessary for the report?*

SCIENTIFIC LITERATURE MINI-CASE

What is primary, secondary and tertiary literature? This can be done in the library or by just borrowing journals from colleagues. For each small group in class have a stack of literature that contains: five journals that contain primary, peer-reviewed scientific literature; two examples of secondary literature (our library has the Annual Review of Microbiology, the Annual Review of Genetics, The Annual Review of Ecology, and Annual Reviews for Psychology); three examples of tertiary literature e.g. Scientific American, Popular Science, Textbooks.

Explain to class:

Type:	***Contains:***	***Author:***	***audience:***
Primary	*First-hand data*	*Researchers*	*Scientists working in that field*
Secondary	*Reviews of primary lit (References primary)*	*Researcher in that particular field*	*Scientists, educators*
Tertiary	*Overview, few references To primary literature*	*Science writer/scientist*	*General public*

Have the students determine to which category each of their 10 pieces of literature belongs. Then have them determine the parts presented in a primary research paper and the information that is contained in each part. You may want to add a tough one, like Science (a primary source that doesn't follow the standard protocol for documentation).

2. *This paper included very specific experimental details, including labeled apparatus diagrams and data tables of measured quantities. Please discuss the importance of including this level of detail in scientific communications. (Why are primary scientific reports so quantitatively explicit?)*

Introduce the notions of reproducibility and verification here. Specific details are required to enable other scientists to repeat experiments, check results, and evaluate experimental conditions. As a follow up question:

3. *In the opening to this paper, Miller emphasized that these experiments were only partial duplications. Please propose a brief list of conditions not considered in Miller's recreation, and (for each) suggest some method to incorporate these conditions into further experiments.*

This is a follow up on question **1** from **Discussion 2**. (Prompt students to review their previous discussion notes if they're slow to recognize this.) Some examples:

Temperature – It's clear from the paper that Miller's pre-biotic Earth model was very fuzzy about actual Earth temperature. Miller might have extended his experiments by running trials over a wide range of temperatures.

Other materials – The Earth was not just atmosphere, but had minerals then, like now. It's known that the surface of solid materials can be chemically active (like the inner surface of Miller's vessel). Miller might have considered adding representative mineral samples to his chemical system.

4. *Figure 8 (paper chromatography of the amino acids) shows that Miller performed several trials of the diagnostic chromatography experiment that he used to identify the amino acids produced in his model pre-biotic atmosphere. Please discuss the importance of performing multiple trials of the same experiment. (Why did Miller repeat the diagnostic chromatography? Why include all the results in this paper?)*

This question addresses the 2nd aspect of experimental reproducibility. Not only should experiments be reproducible by other scientists (for verification), the originating experimenter should repeat them to confirm that the observed results aren't unusual.

5. *The Synthesis of Compounds Identified section describes Miller's control experiments. Please decide what Miller learned from these experiments. (What did he confirm was controlled in his experiments?) It might help to specify that at least two items were confirmed by these supplementary experiments.*

• Miller confirmed that the electrical discharge was required for the formation of amino acids. This was the blank experiment that he described. In the blank run, identical conditions to his other experiments, but lacking the electrical discharge, yielded negligible amino acid production. *As a follow up here: Miller exhaustively discussed whether (or not) the amino acids were actually formed in the discharge through the remainder of this section. Please suggest additional experiments that might have helped him to support his argument that they actually formed in the discharge.*

• Miller also confirmed that microbes didn't produce the amino acids he recovered from the experiments. The blank experiment above contributed to this, as well as another control experiment in which Miller autoclaved his apparatus (and observed normal amino acid production). *As a follow up here: What is autoclaving, and why was this second control required beyond the blank run?* Similar to the discussion above, the microbes might have produced amino acids from other materials formed in the discharge. This second experiment confirmed that microbes didn't act upon either the original materials (H_2, H_2O, NH_3, CH_4) or any new materials formed by the discharge. [FYI, An autoclave is a large pressure cooker that attains temperatures of 120°C. Bacteria that live in our atmosphere cannot survive these temperatures.]

6. *The results of Miller's experiments have been cited as providing an important link between models of the pre-biotic Earth and theories about the chemical origins of life on Earth. Please suggest reasons why this link is important supporting information for any theory about the chemical origins on life. Is consistency between models and theories sufficient positive evidence to increase certainty in their reliability?*

To answer this question, students might need to decide what constitutes a theory of the chemical origins of life on Earth. Essentially, such theories must require appropriate biologically active molecules (certain organic molecules like amino acids) begin to interact with one another. For this to occur, these molecules must have been formed through some inorganic (or non-biological) process. To clarify: We know that life forms can produce organic material from inorganic substances (because of enzymes, etc.), but we do not typically observe the formation of organic material in the absence of life. So, we're asking the question, "Where did the organic material come from in the first place?" Miller's experiments provide one candidate for the type of process that could have formed amino acids (and possibly other biologically important molecules) on the pre-biotic Earth.

As far as consistency is concerned, previous discussions on ways of knowing and tests of verifiability might have prepared students to accept consistency as a criterion for evaluation. However, they needn't substitute consistency for proof. Ultimately, it might be possible to lead them to some reconciliation with the notion that the best scientific model isn't necessarily (isn't ever, really) one on which scientists are absolutely certain.

Homework Assignments: The principal meta-content issues (from the **LEARNING OBJECTIVES**, above) in this case might be reinforced in written responses for homework.

1. *Revisit one of the experimental design issues suggested by the discussion questions. (For examples, question* **3** *in* **Discussion 2** *and question* **3** *in* **Discussion 3***.) Elaborate on a proposed experiment, including especially what experimental controls will be required and what you'd expect to learn from this experiment.*

2. *Paper chromatography is an example of a diagnostic technique by indirect observation. Please propose a brief descriptive list for the types of situations under which scientists might be limited to relying on indirect observational methods. (Provide appropriate elaboration to justify each item on your list.)*

3. *Write a news brief based on* **Reading 2***. (Assume that you're a journalist assigned to communicate the story of these experiments to the broad-based readership of a typical newspaper.) Follow up with a brief paragraph contrasting the content of a typical news story about science with a primary research report from a scientific journal.*

4. *Miller's experimental results provided a link between inorganic volcanic gases that are hypothesized to have constituted the Earth's pre-biotic atmosphere and the formation of organic building blocks for life, especially amino acids. Biochemist (and Nobel Laureate) Thomas Cech demonstrated through another set of laboratory recreation experiments that certain sequences of RNA (ribonucleic acid) can self-replicate (or self-reproduce) in a life-like manner. He has proposed that this chemical behavior might represent the type of pre-biotic chemistry immediately antecedent to the Earth's first life. Please describe the scientific link necessary to connect Miller's pre-biotic organic molecule formation hypothesis with Cech's RNA proto-life system hypothesis. What experiments might be required to provide this link? (Some internet-based research on Thomas Cech and RNA might be appropriate background before approaching this question.)* [References: Thomas R. Cech, "Ribozyme Self-Replication?" *Nature*, **1989**, *339*, pp507-508; Thomas R. Czech, "The Origin of Life and the Value of Life" in *Biology, Ethics, and the Origins of Life*, Holmes Rolston, III, Ed., Jones and Bartlett Publishers: Boston, 1995, pp. 15-38.]

MOLECULAR MODELING MINI-CASE

In *Understanding Scientific Reasoning*, Ronald N. Giere presented an overview of three types of models: Analog, scale, and theoretical. A useful discussion might be to approach these types by asking students to propose descriptions of each, including examples. (A whole-class brain storming session might suffice to complete the models list before starting the actual hands-on activity.) After introducing them to molecular models (with one or two trial molecule assemblies), the case discussion should return to the model types: Under which type, or types, of model (from Giere's list) do molecular models belong? (Discussion question **3** below) Hopefully, students will discover that molecular models have elements in common with each type of model. Ultimately, then, scientific models adjust representation (analog models), adjust scale for convenience (scale models), and are also useful for making predictions (theoretical models).

[Ronald N. Giere, *Understanding Scientific Reasoning, 4th Ed.*, Harcourt Brace College Publishers, 1997.]

Activity: Distribute molecular model kits, one per person. (Alternately, two or three kits per discussion group.)

[Model kits: The Department of Chemistry has wooden ball-and-stick style organic molecule modeling kits from Fisher Scientific. Because these model kits are used for some classes, it will be important to schedule this activity well in advance – at the beginning of the semester, if possible. Contact the Department of Chemistry to request the model kits.]

1. *Please use the model kits to construct a model for the molecule with formula C_3H_8. The only rule for this activity will be that no holes are to be left open, no sticks uncapped. Each ball represents one atom, each stick one atom-to-atom connection. Once the models are completed ask students to compare models within (and between) discussion groups. Ask, "Are all the models in the room the same?"*

Yes and No. The absolute configurations of the models will all be slightly different because they can be rotated about the sticks connecting adjacent balls. So the question becomes, "Are these models truly analog models in their representation that molecules are able to change shape by rotating around their own bonds?" The answer to this question required extensive experimentation, but it is known that molecules are rather floppy. They rotate and also bend and vibrate. (A more accurate analog model would be wooden balls connected by springs.) Understanding this, it becomes only the connectivity that changes from molecule to molecule, with absolute configuration continually varying wildly for every individual molecule – the models in the room should all be the same molecule.

2. *Now, from your C_3H_8 models, construct models for C_4H_{10}. Again, compare models within (and between) discussion groups. Ask, "Are all of these models the same?'*

Unlike the previous model, C_4H_{10} has two possible structures (two possible connectivities). With any luck, some students will have assembled a model with all four carbons in an unbranched chain, while some others will have made the branched-chain isomer (alternate model). These two models represent molecules with very different properties. This is the real advantage to working with 3-D molecular models – the ability to see structural differences that might not have been obvious from simple chemical formulas.

3. *Please consider the simple set of model types: Analog, scale, and theoretical.* (Alter this list to suit instructional tastes.) *Under which type, or types, of model do molecular models belong? Provide justification for your response.*

4. As a model-building finale, provide the students with 2-D representations of relevant chemical structures (amino acids for the **Organic Soup?** case, or nucleic acids for *The Double Helix* case). Ask them to use the molecular model kits to construct models for these materials. Comparing the structures of the five amino acids identified by Miller might be interesting: Chemical differences obvious from the molecular models lead to their different separatory properties that allowed Miller to identify them by diagnostic chromatography. Models of the nucleic acids are a little harder to assemble (due to double bonds and tight rings): This provides some insight into the difficulties that Watson and Crick would have faced with their own model building.

CASE 6: FIVE MICRO-EVOLUTIONARY POINTS (2 TO 2½ WEEKS)

Background: This two-part case approaches the issues related to **Experimental Design in Micro-Evolution**. Darwin's book, *The Origin of Species*, explains evolution as a process with natural selection as the mechanism. Five points must be verified for the mechanism to be acceptable.

1. Certain organismal traits are inherited, i.e. human beings have human babies as opposed to gorilla babies
2. In most species only a small portion of the individuals in each generation survive and reproduce.
3. There are chance variations in individuals that are not a product of the environment (mutations). The fluctuation test that was designed by Luria and Delbruck provides evidence for this assumption.
4. Some variations allow certain individuals to produce more offspring in a specific environment (natural selection). Those variations will become more and more common in succeeding generations. This is also called microevolution. Kettlewell's paper is one of the classics, and it provides evidence for this assumption.
5. With time, an accumulation of changes would result in groups that could be distinguished from one another (new species). The fossil record provides evidence for this. [This point might provide the basis for instructors to elaborate on this case with additional material. Perhaps, students might be asked to do library research for information to support this point.]

Preliminary Discussion: Preliminary in-class discussion might include review of the five points and solicitation of proposals from students for observations or the types of observations that might be required to verify the points. This is an extension of the notions of verifiability and ways of knowing addressed in CASE 1 and CASE 2. This case includes two sections that address points three and four with readings and in-class exercises.

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Luria and Delbruck's Fluctuation Test (1 - 2 class periods)

Reading 1: An excerpt from *An Introduction to Genetic Analysis*, 7th edition (pp 479-481) as a one-page summary for students to read in class. [This summary is included with this report as a one-page handout for instructors to photocopy – an appendix to this case study. Note to instructors: Students will require some assistance understanding the material, and some explanation with illustrative diagrams might be appropriate. This is an extension of material from Chapter 2 (page 44) in Giere's *Understanding Scientific Reasoning*, and instructors using the Giere text might point this out to their students.]
Reading 2: Mutations of Bacteria from Virus Sensitivity to Virus Resistance (1943) S.E. Luria and M. Delbruck *Genetics* 28:491.

LEARNING OBJECTIVES

(1) Continue the survey of experimental design issues.
(2) Have students identify the models (hypotheses) that are being tested after reading the introduction from a primary research article.
(3) Measure and graph variance, demonstrating that the degree of variance in an experiment leads the experimenter to accept or to reject models.
(4) Examine the foundational premises necessary for a scientific model (in this case, Darwin and Wallace's concepts of evolution).
(a) The fluctuation test addresses the premise that mutations are not induced in the individual by the environment, but are dispersed randomly throughout the population.
(b) Kettlewell's paper in the following case addresses the premise that favorable variations (mutations) tend to become more common from one generation to the next (natural selection).

OUTLINE FOR READING 1

Two models are presented for finding mutations in an environment. In the random mutation model the mutations arise spontaneously without environmental influence and are present in the population. In the physiological model the mutations arise in response to an environmental stimulus. For example:

Model A: Bacteriophage (bacterial virus) resistant bacteria exist in a small proportion of the total population. The mutations arise without prior exposure to bacteriophages.
Model B: Bacteriophage resistant bacteria arise after the bacterial population is exposed to bacteriophage.

CASE PLAN

Reading/Homework: Have the students read the introduction in Luria and Delbruck's paper (Reading 2). They must write the two models in their own words. They will need the following information.

Bacteria are grown as a population in a liquid culture. Mutants can be measured by exposing a bacterial culture to bacteriophage and plating the mixture on an agar lawn on a petri dish. Only resistant bacteria will grow into a colony. Thus, bacteriophage-resistant bacteria can be quantified by counting the colonies.

Spend time pointing out the models in the introduction in class.

Teaching Notes: I put the paper on hard copy and electronic reserve at Tarver library. My students had a horrible time accessing the paper. Many of them ended up checking it out from the reference desk. They understood the introduction for the most part. They had a hard time finding the two models, because the authors make many hypotheses.

<u>Class Exercise:</u>

(1) Distribute materials to each group of 3 students:

- One six-sided die
- One copy of **Sheet 1** (two sets of 4 cultures that have 5 generations represented)
- Three copies of **Sheet 2** (Histogram)–one for each student
- **Reading 1**

(2) One student is asked to choose a number between 1 and 6, and that number becomes the number that would give rise to a mutant culture. If the student chooses 3, then every time a 3 is rolled the students should darken that individual in the diagram on Sheet 1, i.e. that individual has a mutation.

(3) For Model 1 (the spontaneously arising mutation model) the die will be rolled for each individual represented on Sheet 1, beginning with generation 1. Once a mutation arises in an individual, all of his descendants should be darkened and the die will not have to be rolled for them. Students should work their way down the generations on Sheet 1, rolling for each un-mutated individual.

(4) For Model 2 (the physiological response model) the die will be rolled for each individual represented on Sheet 1 in the last generation only – because mutations can only arise in response to the environmental component in this model.

(5) After the students have rolled the die and filled in the two models, the numbers can be recorded on the board. Histograms can be filled in to see the distribution of numbers of mutants per culture (Sheet 1). Model 1 should yield a large degree of variance and Model 2 should yield minimal variance. Ask the student groups to compare their results with respect to the amount of variation, and then to compare their results with the data from the Luria-Delbruck paper, Reading 2. [The actual data resembles Model 1. See also the **Sample Histogram** that was prepared by SCI 105 students for this case.] The students should recognize that the amount of variance can be used to distinguish between the two models.

[The figures **Sheet 1**, **Sheet 2**, **Sample Histogram** are appended to this case study for instructors to photocopy.]

Discussion: Typically an entire class period is required to complete this exercise. One possible follow-up question for discussion is: "For what other items might variance tests be used?"

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Kettlewell's Selection Experiments (2 class periods)

Reading 1: H.B.D. Kettlewell, Selection Experiments on Industrial Melanism in the *Lepidoptera*. Foundations of Ecology–classic papers with Commentaries, ed. Leslie Real and James Brown (a Jack Tarver Holding)
Reading 2: A textbook synopsis of the Kettlewell paper from Curtis and Barnes 5th edition, Biology (Worth publishers)

<u>LEARNING OBJECTIVES</u>

(1) Continue with the survey of experimental design with a case that contains both laboratory and field experiments. The students will gain an appreciation for both approaches and determine that values and pitfalls of each type of experimentation.
(2) The case paper contains an ample of amount of data with which the students can perform "quick and dirty" or more sophisticated statistical analyses (Giere's chapters 5 and 6).

(3) The results can be used to make further predictions, i.e. the scientific process continually leads to additional experimentation.

OUTLINE FOR READING 1

Hypothesis: Selective elimination by predators results in evolutionary change.
Experiment: Both field and laboratory experiments done. The dark form and the white form of the peppered moth were released in areas of dark tree trunks (polluted areas) or light tree trunks (natural form). The percent recaptured were measured.
Results: More light moths survived in the light-trunk area and more dark moths survived in the dark-trunk area.
Interpretation: Polluted areas that have dark trees allow for selection of the new dark form of moth.

CASE PLAN

Reading/Homework: Assign the following homework assignment and collect/discuss the answers in class the next day.

Go to the library and read the article by Kettlewell. (Of course, they will need the reference, or else a copy must be put on reserve for the class.) *The article is a classic paper and is often quoted when scientists discuss microevolution. Please read the paper and answer the following questions. You may want to discuss the questions with group members before you attempt to write your own individual answers.*

1. Why did Kettlewell do experiments in a laboratory setting?
[Controls all of the variables, easier, cheaper.]
2. Why did Kettlewell do field experiments (in a natural setting)?
[Allows one to see unforseen variables that may affect results.]
3. Which experiments, field or laboratory, are more important? What are the advantages and disadvantages of both styles of experimentation?
[Both are very important. Laboratory experiments allow the investigator to change only one variable at a time. An effect would then be due to that variable. Field experiments allow the scientists to see if their predictions from a laboratory experiments hold true in the real world.]
4.Why are there so many numbers in this paper i.e. why is this work quantified?
[The language of science must be consensible (precise, concise, and unambiguous) and numbers are the best tool that we have. The experiments are then repeatable and the level of significance can be tested.]
5. Why did Kettlewell collect the data for Table 6?
[To show that the two variations (light and dark moths) are equally attracted to the MV lamp.]

Class Exercise:
(Adapted from the Biology Department notes for BIO 115)

After the students have read the Kettlewell article and discussed it in class, ask them to completely describe each of the following “scientific method” activities as undertaken by Kettlewell: **Observations**, **Hypothesis**, **Predictions**, and **Experimentation** (including data, or results). Typically, student discussion groups will need prompts and guidance from the instructor – an example set of activities descriptions is provided below.

Observations: New species can arise when differences among the individuals within a population are gradually converted into differences between groups. Kettlewell’s work with the peppered moth is a good example of this. Kettlewell made some initial observations.

1. The peppered moth was usually found on lichen-covered trees and rocks. The light coloring of the moths made them nearly invisible on the lichen surface. Until 1845 all peppered moths were light colored.

2. In 1845 a black form of the moth was found in an industrial center of England. Pollution from industries killed the lichen in the area and left the trees bare, and some trees became black with soot.

3.Where did the black moths come from? It was later discovered that they had existed in the population, but in very small numbers. The black color was the result of a rare mutation.

Hypothesis: Kettlewell developed a hypothesis (a tentative explanation to be tested).

The color of the moths protected them from insect-eating birds.

Predictions: If he released both light and dark moths in a polluted area, he would recapture more dark moths than light moths. If he released both light and dark moths in an unpolluted area, he would recapture more light moths than dark ones.

Experimentation:

1. He marked both light and dark individuals of the species by putting a spot on the underside of the wing.
2. He then released a known number of both kinds into a polluted area or an unpolluted area.
3. He recaptured the moths using a light trap at night.

	Polluted	**Unpolluted**
Light-colored moths	19 %	12.5 %
Dark-colored moths	40 %	6.0 %
Total N	59	18.5

Discussion Question: *If he began with 100 light-colored moths and 100 dark-colored moths, use the quick-and-dirty method to determine if this is a statistically significant difference. Would your answer change if he had released 1000 of each type?*

More Experimentation – If Time Allows: To provide more evidence for his hypothesis, Kettlewell also placed moths on tree trunks in both areas and watched through a hidden camera, and recorded that birds actually selected and ate the more conspicuous form.

	Polluted	**Non-polluted**
Light moths eaten	43	26
Dark moths eaten	15	164

Discussion Question: *Are these numbers statistically significant?*

Concluding this Case:

Conclusion/Summary: Ask for conclusions. [Moth survival is greatest when their color matches that of the environment.]

Future Predictions: *Make several future predictions about the moth population in these areas.*

Additional Discussion: *What are important items to know when checking statistical data?* Ask student discussion groups to list them and to describe the impact of each item. [Items will include sample size, margin of error, etc.]

Recent Debate: There has been some debate about the validity of Kettlewell's experiments involving the placement of moths (**More Experimentation** section above). The web address below connects to a *New York Times* article by Nicholas Wade (June 18, 2002) that summarizes the debate. Each student discussion group might be asked to consider this argument and its impact on their certainty in Kettlewell's findings and in rapid microevolution.

http://www.nytimes.com/2002/06/18/science/life/18MOTH.html?ex=1025450792&ei=1&en=e30b5e3f96d5b586

Homework 2: One of the homework assignments that we discussed involved sending students to the primary literature to locate papers and write brief reports. An abbreviated form of this assignment (just the report) was included with CASE 5. A possible homework assignment with which to close this case is: *Obtain a primary article on microevolution—a species changing from one morph (form) to another from environmental selective pressure. Bring a photocopy of the article to the next class period (The instructor should check that it is a primary research article.). Write a news article for a newspaper like the "Macon Telegraph" to communicate the information in your paper to the general public.*

Luria and Delbruck's Fluctuation Test – Reading 1

[Excerpted from Anthony J.F. Griffiths, Jeffrey H. Miller, David T. Suzuki, Richard C. Lewontin, and William M. Gelbart, *An Introduction to Genetic Analysis*, *7th Edition*, pp 479.]

"Mutations (define) that confer resistance to specific environmental agents not normally tolerated by wild types (define) are easily demonstrated in microorganisms. We shall use an example that was important historically in determining the nature of mutation.

"The intestinal bacterium *E. coli* is parasitized by many specific phages (define). One of them, called T1, was used in early bacterial mutation studies. Phage T1 attacks and kills most *E. coli* cells, liberating a large brood of newly synthesized progeny viruses (define) from each dead bacterial cell. If a plate (define) is spread with large numbers of bacteria (about 10^9) mixed with phages, most of the bacteria will be killed. However, some rare bacterial cells survive and produce colonies (define) that can be isolated.

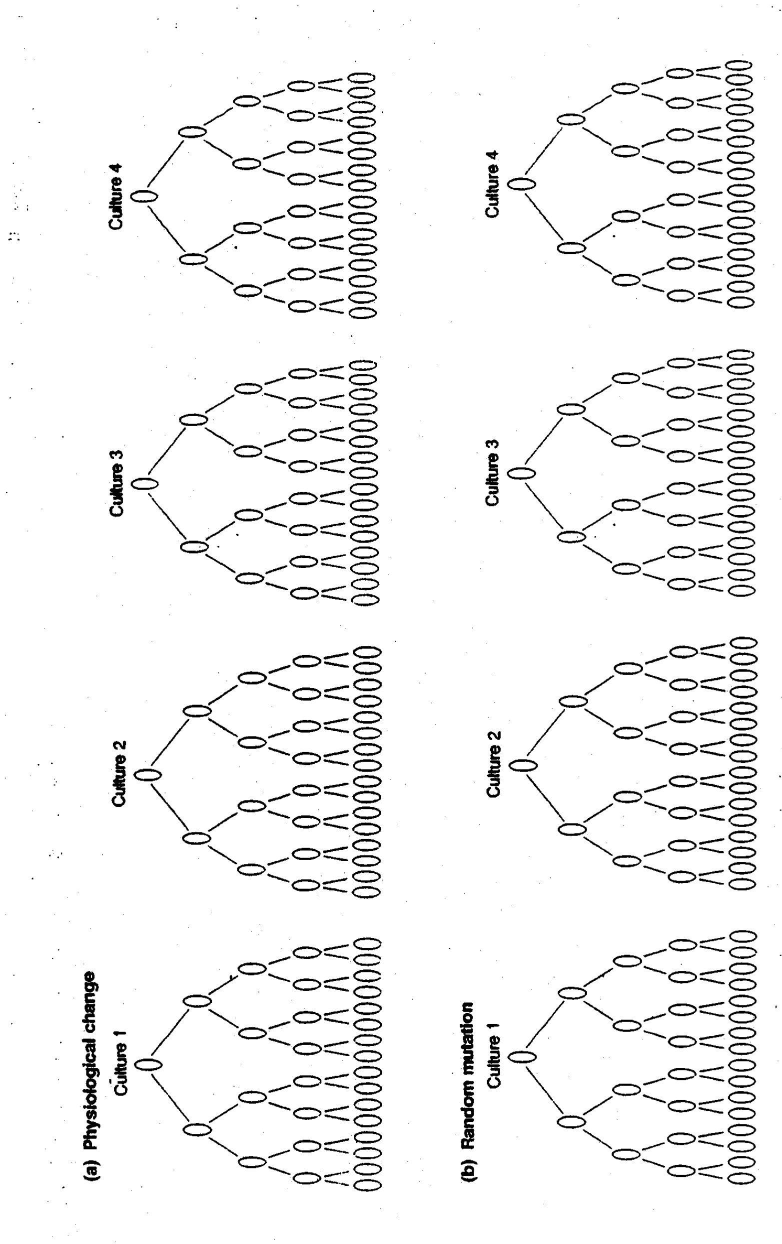
"When T1-resistant bacteria were first observed, their origin was not known, but there were two main hypotheses. First, the resistance could be due to random mutation from a wild-type allele (define) conferring sensitivity (Ton^s) to a mutant allele conferring resistance (Ton^r). Second, the bacteria could somehow sense the presence of the phages and adjust their cellular physiology in such a way that some cells might succeed in becoming resistant. This adjustment could be similar to the manner in which bacteria shift their physiology to utilize a new nutrient in the medium. In 1943, Salvadore Luria and Max Delbruck designed a classic experiment to distinguish between these two hypotheses. Their experimental design was called a **fluctuation test**. Not only was the fluctuation test historically important in determining the origin of phage-resistant bacteria, but it also provided a method for calculating mutation rates (define) that is still used today.

"Luria and Delbruck reasoned that the two hypotheses of mutation and physiological change gave different predictions about the numbers of resistant bacteria found in a sample of cultures. Under the mutation hypothesis, in the cultures where a rare mutation event occurs, the mutation event could occur relatively early or relatively late in the growth of the culture because, presumably, mutation is random over time. An early event would produce a larger clone (define) of descendent resistant cells than would a late event. Hence, considerable variation in the number of resistant cells from culture to culture is predicted (Luria and Delbruck used the term fluctuation instead of variation). Under the physiological change hypothesis, there is no reason to expect such variation; the physiological gear shifting would presumably be quite constant.

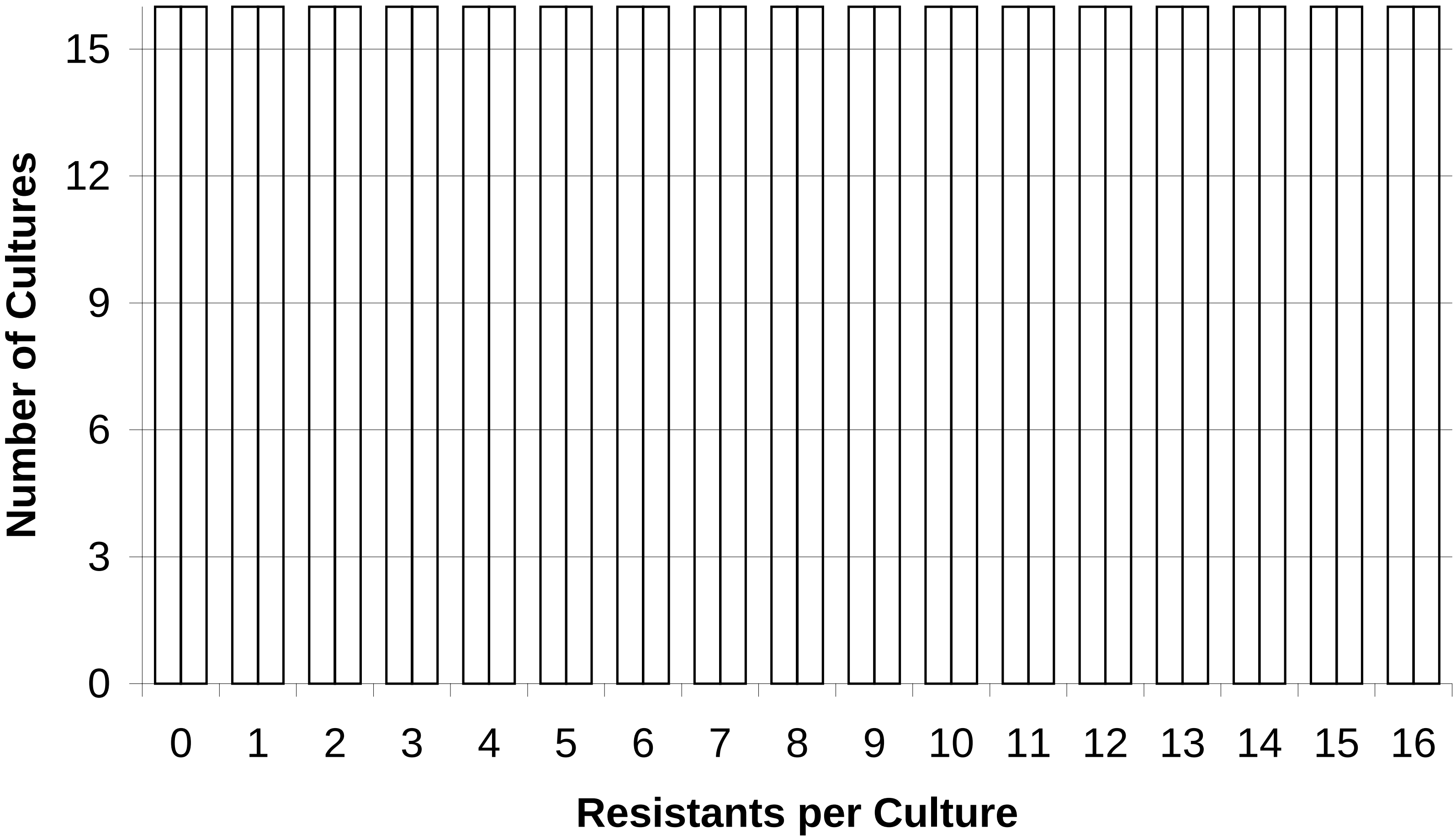
"The practical details of the experiment were as follows. Into each of 20 culture tubes containing 0.2 ml of medium and into one containing 10 ml, they introduced 10^3 *E. coli* cells per milliliter and incubated them until about 10^8 cells per milliliter were obtained. Each of the 0.2-ml cultures was then spread on a plate that had a dense layer of T1 phages. From the 10-ml "bulk" culture, 10 separate 0.2-ml volumes were drawn and plated."

[Additional material needed on this page?]

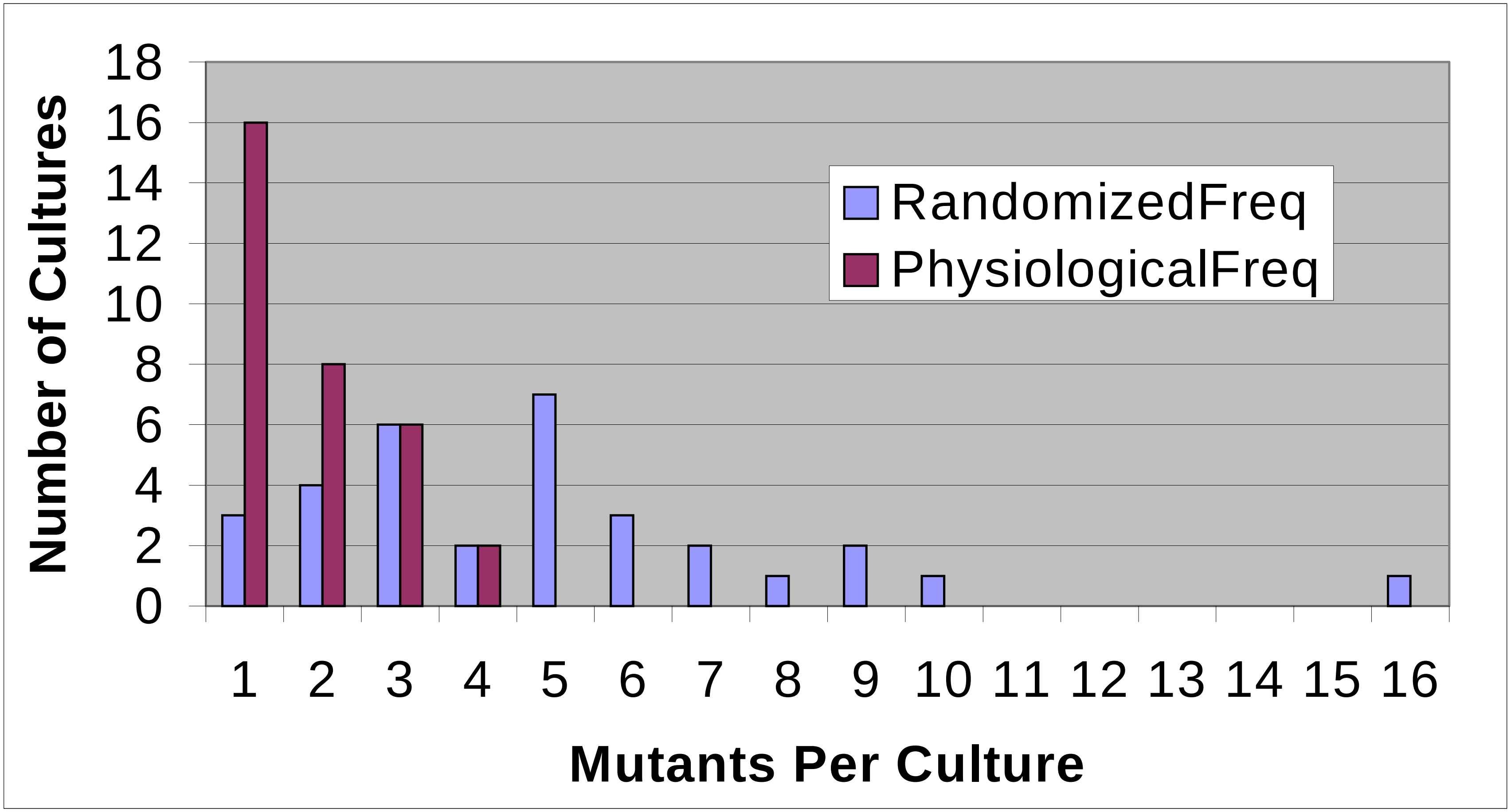
Luria and Delbruck's Fluctuation Test – Sheet 1



Luria and Delbruck's Fluctuation Test – Sheet 2



Luria and Delbruck's Fluctuation Test – Sample Histogram



(Data from Linda Hensel's SCI 105 class.)