HISTORY OF SCIENCE

EDUB 1760 (Education) and PHYS 2700 A01 (Physics) (3)

Winter Term 2009

Location: Rooms: 224 and 300, Education.
Time: 5:30 - 8:30 PM, Wednesdays

Instructor:
Dr. Arthur Stinner,
Professor of Science Education
Faculty of Education, Room 237, (474-9068).

E-mail:
Stinner@cc.umanitoba.ca

Websites:
www.ArthurStinner.com
www.Sci-Ed.ca

Office Hours: To be announced

Course Description:
This course looks at the historical development of science in terms of the big ideas of the times, the contemporary mode of scientific reasoning and what was considered empirical evidence to support these big ideas. Three historical periods are studied:

1. **Greek Science** (sixth century BC to the second century AD);
2. **The scientific revolution** (from about 1500 to about 1700); and
3. **Modern science** (from about 1700 to about 1810).

Based on class discussions of these historical periods students will design case studies to present to class. These case studies can be seen as contributing to a deeper understanding of science as well as providing contexts that allow the development of hands-on teaching that can be used in the science classroom. The pedagogical assumption for creating these contexts is based on recent findings in science education. Research strongly suggests that the nature of conceptual change in science are fundamentally the same in the *discovery* and in the *learning* processes.

What counts as achievement in science in a given historical context will have to be defined, as well as the science methodology used clarified. In highlighting an achievement, such as Archimedes' law of flotation, for example, the richness of the historical setting will be emphasized. This will be accomplished partly by comparing actual achievements with typical textbook versions. Moreover, by imposing the framework of *contexts of inquiry* on investigations of the science of an era the "process" and the "products" of science are studied *together,* rather than separately as in most courses in science and science education. In conclusion, this approach will acquaint the future science educator with historical context, the nature of science and the educational possibilities in presenting all this to the young science student.

Resource Materials:

1. Main reference books:

a. *A Short History of Science to the Nineteenth Century*, by Charles Singer. Available in paperback at the University Bookstore.

b. *Harvard Project Physics*. Available in the Science Library (4 copies) and in the Science Library (2 copies) as reference books only (3 hours).

c. *Making Modern Science*, by Peter Bowler and Iwan Rhys Morus (2005). Available in the Science Library (4 copies).

2. Secondary Reference Books**:**

a. *A History of the Sciences*, by S. Mason. Available in the University bookstore.

b. *Science: Its History and Development Among the World's Cultures,* by Ronan.

3. Simple laboratory equipment available in conventional science labs.

4. Articles available in such journals as *Science Education*, *Science & Education, Science Teacher, Science and the Child, Chemistry Teacher, Biology Teacher, Scientific American, Physics Teacher, Physics Education*, *International Journal of Science Education, American Scientist,* and *New Scientist.*

5. The Internet: Reflective and judicious use of the Internet is expected.

Course Objectives:

1. To give the student a fine sense of science history, according to the injunction of Thomas Kuhn (the introductory sentence of his famous *The Structure of Scientific Revolutions*):

History, if viewed as a repository for more than anecdote or chronology, could produce a decisive transformation in the image of science by which we are now possessed.

2. To acquaint the student with the richness of the scientific imagination that the conventional science study in formal courses based on textbooks cannot give.

3. To provide the student with an opportunity to engage in several small exercises of original historical research in science by way of presenting a case study.

4. To have the student develop an appreciation for the difficult task scientists had to face in *every* historical period in trying to understand the world.

5. To assist the students in developing a number practical, hands-on contexts, in which young students can learn to engage the world according to their own predilections and understanding.
6. To give prospective science teachers a background for applying the findings of the history (and some philosophy) of science to their every day teaching.

7. To give students a good understanding of the nature of science, especially the deep connection between *science content* and *science processes* .

8. To help students develop the habit of looking at scientific activity by way of the *Contexts of Inquiry* approach that **implicitly** contains such conventional process notions as *observation, inference, hypothesis, theory, and experiments.*

A thematic approach will be used, based on the presentation of the "big ideas" of science, and when possible, key- experiments that support these ideas.

More Details about the course:

The time allotted for the course is about 40 contact hours. Each session will be 3 hours long. About 9 of these sessions will be spent in a demonstration and experiment-based lecture and discussion. About 2 sessions will be devoted to student presentations of case studies. A two hour period will be used for a final examination, outside class time.

For each lecture and discussion session a cluster of topics will be chosen under a unifying idea or theme. As much as possible hands-on activities will be planned (demonstrations, experiments) that involve the students. One of the main objectives will be to set the stage for students to pick a case study for later presentation and the final development of a large context problem or "science story".

ASSIGNMENTS:

Assignment Format:

Suggested exercises in **Class Assignments must** be typed and neatly presented. The cover sheet must identify the assignment as well as bear the name of the instructor. Assignments must be handed in on or before the agreed schedule of dead lines.

ASSIGNMENT I.

(Groups of 2) Value: 20%

Students will be asked to form groups of two and prepare *historical contexts*, taken from the three historical periods we are discussing. The format as well as the content of these are discussed in the section called *Historical Contexts* on page 22-23. You will be required to make one presentation only Presentations should be done in PP accompanied by demonstrations.

These contexts will serve to initiate and encourage class discussion.

Students should summarize their presentations on **1 page only** (both sides) and hand these out to each member of the class, before the beginning the presentation is given..

ASSIGNMENT II:

Value: 15%
(Groups of two)

Reading assignments:
There are 4 reading assignments. Hand in only assignment 1 and 4.

ASSIGNMENT III:

Value: 25 %
(Groups of two or three, depending on the size of the class).

A CASE STUDY (See pages 19-20).

To be done as a PP presentation.

Your Task: For a case study presentation students will be asked to form groups of three (with at least one education student in the group) and make a commitment for planning a case study. This commitment will be made no later than the middle of the lecture-discussion phase. Each group will be asked to present the case study in three parts, one part prepared by each student:

HISTORICAL CONTEXT :
Student No.1 presents the scientific ideas of the historical period and how they are connected to the topic.

THE EXPERIMENT(S) AND THE MAIN IDEAS: Main ideas and/or empirical support for what is central to the case study is presented by student No.2, assisted by his/her colleagues. If possible, these demonstrations should also involve the students in the audience.

IMPLICATIONS FOR SCIENTIFIC LITERACY AND THE TEACHING OF SCIENCE: Student No.3 responds to the following questions: where do the concepts fit in the science curriculum? How can we operationally connect the logical plane of activity with the evidential plane? What are the diverse connections of the concepts under discussion?

Each of the three students must hand in a type-written report, one for each of the sub-presentations (3-5 pages).

ASSESSMENT:

ASSIGNMENT I (Historical Contexts):	20%
ASSIGNMENT II (READINGS)	15%
ASSIGNMENT III (Case Study)	25%
MIDTERM TEST	15%
FINAL EXAM	25%
	100%

Final letter grades will be determined as follows:

A+	95-100	Exceptional
A	90-94	Outstanding
B+	85-89	Excellent
B	80-84	Very good
C+	75-79	Good
C	70-74	Satisfactory
D+	65-69	Pass
D	60-64	Borderline
F	<60	Fail

TOPICAL OUTLINE AND DAILY PRESENTATIONS:

The following is only a suggested content for presenting the course using *themes* or *big ideas* that will help the organization of each two hour session.

Refer to the Calendar for the course.

I. Greek Science

DAY 1:

Introduction to the course.

1. **Aristotle's physics of motion: A sample context, presented by instructors.**
2. **Free fall of light and heavy objects.**
3. **Aristotle's anticipation of the law of inertia.**
4. **His notion that forces are either natural or violent.**
5. **His insistence that terrestrial physics and celestial physics must be separated.**

References:

Read pp. 1-31 in Singer and Mason, Chapters 1,2 and 3.

1. Text: Mason, S., *A History of the Sciences*, Chapters 2,3.
2. Other Sources:

a. "Democritus and the Atom", *Scientific American,* 1949, p. 48.
b. Ronan, C. *Science: Its History and Development Among the World's Cultures (1981).* See Bibliography.
c. *The World of Mathematics*, Newman, Vol. 1., pages 41, 94, 99, 165.
d. "Resolving Zeno's Paradoxes", *Scientific American*, Nov. 1994.

DAY 2:

"THE WORLD IS RATIONAL AND CAN BE UNDERSTOOD BY THE POWER OF REASONING"

Suggested Topics:

1. The beginnings of geometry.
2. Pythagoras and he mathematization of the world.
3. The three laws of physics that the Greeks discovered.
4. The three unsolved problems in Greek mathematics.

● Thales and his geometry, anticipating the deductive thinking of Euclid.

● Pythagoras' ideas about how mathematics relates to the world. Demonstration of this relationship using musical instruments. \

● The three laws of physics that the Greeks discovered:

1. Archimedes: The Law of Reflection,
2. The Law of the Lever, and the Law of Flotation.
3. The three unsolved problems in Greek mathematics. Examples to the modern (19th century) solutions to the three outstanding mathematical problems discussed.

Read Singer, Chapter 2 and Mason, Chapters 4 and 5.

1. Text: Chapters 4,5.
2. Other Sources:

a. "Aristotle's Physics", by Carl B. Boyer, in *Scientific American,* May, 1950.
b. "Aristotle: Villain or Victim?", by Carl G. Adler and L. Coulter, in *The Physics Teacher,* Jan., 1975.
c. "Greek Astronomy", by G. de Santillana, in *Scientific American,* April, 1949.

DAY 3

I. Greek Science...

MODELLING AND MEASURING THE UNIVERSE

Suggested Topics:

1. "Measuring" the size of the earth.
2. How the Greeks measured the distances to the moon and the sun.
3. Aristotle's physics of motion (presented by instructors).
4. Aristotle's biology.
5. The Ptolemaic model of the solar system.

The story of how Eratosthenes "measured" the size of the earth. How the Greeks calculated the distance to the moon and to the sun. Why the Greeks were unable to find the distances to the planets.

Plato's cosmological question:
By the assumption of what uniform and ordered motions can the apparent motions of the planets be accounted for? A problem in geometric modelling.

The Ptolemaic solar system: the most successful response to Plato's cosmological question.

Determination of the length of the year: Eudoxus and Hipparchus. The circumference of the earth: Eratosthenes.

Central Activities: Groups working on models and drawings illustrating Ptolemy's solution to Plato's problem and how the sizes of the earth, moon and the sun, and the distances between them were determined. The problem of scaling will be illustrated.

References:

1. Text: Read Singer, Chapter 3 and Mason, Chapters 4 and 5.
2. Other Sources:

a. Ronan, C. (1981).
b. Hall, A.,R. (1964). *A Brief History of Science.*
c. Sedgewick, W.T. (1929).
d. Project Physics (1969), Chapter 5.
e. Exploration of the Universe. Abell.
f. Any contemporary astronomy text.

II. THE SCIENTIFIC REVOLUTION

DAY 4:

Part A: TWO MODELS: THE GEOCENTRIC AND HELIOCENTRIC SOLAR SYSTEMS

Suggested Topics:

1. **Copernicus' model of the heavens**
2. **Kepler's laws of planetary motion**
3. **Galileo and his telescope: "The Starry Messenger"**
4. **Harvey's discovery of the circulation of the blood**

The Important contributions to modern science of the natural philosophers of the middle ages
Aristarchus: "The Copernicus of Antiquity". Copernicus and the heliocentric solar system.
Tycho Brahe's instruments for measuring planetary positions

Central Activities: Copernicus' heliocentric model is compared to the geocentric model of Ptolemy. Tycho Brahe's exemplary naked eye measurements are discussed with reference to accuracy. A simplified reconstruction of Kepler's twenty year quest to establish his laws will be presented. The fascinating history of the quest for a routine method to establish latitude on board of a ship will be discussed.

References:

1. Read Singer, Chapter 7 and Mason, Chapter 12

2. *Project Physics* (1970), Chapters 6 and 7.

3. Other Sources:

a. "The Scientific Revolution" by Herbert Butterfield, in *Scientific American*, Sept. 1960.
b. "The Origins of the Copernican Revolution", By Jerome R. Ravetz, in *Scientific American,* Oct. 1966.
c. "Giordano Bruno", by Lawrence S. Lerner and Edward A. Gosselin, in *Scientific American*, Nov. 1986.
d. "The Celestial Palace of Tycho Brahe", John Christianson, in *Scientific American,* Febr. 1961.
e. "Medieval Roots of the Industrial Revolution", by Terry S, Reynolds, in *Scientific American,* July, 1984.

DAY 5:

II. THE SCIENTIFIC REVOLUTION...

Part B: THE SCIENTIFIC REVOLUTION:

THE BEGINNING OF EXPERIMENTAL PHYSICS

Suggested Topics:

1. Galileo's inclined plane experiment
2. Torricelli's experiment: "The weight of the atmosphere".
3. Boyles' law: "Testing the Springiness of Air".
4. Newton's laws of motion.
5 One day in the life of Robert Hooke, FRS, the secretary of the *Royal Society*.
6. Roemer's determination of the speed of light.

References:

1. Text:_ Read Singer, Chapter 7 and mason, Chapters 21 and 22. Read Singer, Chapter 8 and Mason, Chapters 14, 15, 25.

2. Other Sources:

a. "Robert Hooke", by E.N. da C. Andrade, in *Scientific American,* Dec. 1954.
b. "William Harvey", F. Kilgour, in *Scientific American*, June 1952.
c. Robert Boyle, by Mary Boas Hall, Scientific American, Aug. 1967.
d. "The Measurement of the Spring of the Air", in *Great Scientific Experiments*, by Rom Harre

e. "Galileo's Discovery of the Law of Free Fall", by Stillman Drake, in *Scientific American*, May, 1973.
f. "Newton's Discovery of Gravity", by I. Bernard Cohen, in *Scientific American*, March, 1981.
g. "Isaac Newton", by I. Bernard Cohen, *Scientific American* (Dec. 1955).
h. "Galileo", by I. Bernard Cohen, *Scientific American* (Aug. 1949).
i. "Problem in Two Unknowns: Robert Hooke and a Worm in Newton's Apple, by Robert Weinstock, *The Physics Teacher,* May, 1992.
j. "Newton's Apple and Galileo's Dialogue, by Stillman Drake, *Scientific American*, (Aug. 1980).

<u>III. MODERN SCIENCE</u>...

DAY 7:

Part A: THE NEW CHEMISTRY
Part B: ATOMIC THEORY OF MATTER

Suggested Topics:

1. **"A day in the life of an alchemy**
2. **The development of modern chemistry, from Lavoisier to Dalton.**
3. **Count Rumford and the caloric theory of heat.**
4. **Dalton's atomic theory.**

Experiments to illustrate a confrontation between the phlogiston theory and Lavoisier' new chemical theory. Experiments of Priestley and Black. Demonstration of the production of oxygen, carbon dioxide, and hydrogen. Lavoisier's heat theory. and hydrogen. Illustration of the Law of Multiple Proportions.

Dalton's assumptions, his observations and his experiments which led to his atomic theory of matter. Davy's experiment: separating water by an electric current. Avogadro's hypothesis and Gay-Lussac's law of combining volumes . All this leads to Mendeleev and the periodic table of the elements.

References:

1. Text: Read Mason, Chapter 26 and Singer, pp. 283-296, and Mason, Chapters 26, 27.
Read Part 1, 3, The Chemical Revolution in Bowler and Morus.

2. Other Sources:

a. "Alchemy and Alchemists", by John Read, in *Scientific American,* Oct. 1952.
b. "Lavoisier and the Theory of Combustion", by Homer W. Schamp, Jr. in *The Science Teacher,* Sept. 1988.
c. "Lavoisier", by Denis I. Duveen, in *Scientific American,* May 1956.
d. Ronan, R. (1981).
e."Where Credit is Due-The Energy Conservation Principle", by V. Raman, in *The Physics Teacher,* Feb. 1975.
f. "Lord Kelvin demonstrated" by J.T. Lloyd, in *The Physics Teacher,* Jan. 1980.
g. "Benjamin Thompson, Count Rumford" by Sanborn C. Brown, in *The Physics Teacher,* May, 1976.
h. "The Invention of the Balloon and the Birth of Chemistry", by Arthur F. Scott, in *Scientific American,* (Jan. 1984).
i. "The Age-of-the-Earth Debate, by Lawrence Badash, *Scientific American*, Aug. 1989.

DAY 8:

<u>III. MODERN SCIENCE</u>...

BIOLOGY FROM THE LATE 18th TO THE MIDDLE OF THE 19th CENTURY

1. **Stephen Hales and *the circulation of sap in plants.***
2. **TheCell Theory and the question of spontaneous generation of life.**
3. **Darwin's "Voyage of the Beagle".**
4. **Lord Kelvin and the Age-of-the-Earth Controversy.**

Linnaeus: system of classification in biology that was then further developed by Lamarcke, and is essentially still used today.
Lamarcke and Erasmus Darwin: theory of evolution and Cuvier's belief in the fixity of species.
Darwin's journey on the Beagle. Darwin's "Theory of Evolution".

Central Activities: Discussion of the "scientific method" used by Dalton to establish his atomic theory. He seems to have based his arguments on a number of assumptions, each of which were either logically fallacious, or physically wrong. Separation of water into hydrogen and oxygen will be demonstrated. Discussion of why Avogadro's hypothesis and Gay-lussac's experiments strengthened atomic theory. The story of Mendeleev's attempt to build an organizing model based on the physical and chemical properties of elements.

1. Text: Read Mason, Chapter 36.

2. Other Sources:

a. Any elementary textbook of chemistry that discusses the historical development of atomic concept
b. "Elementary Chemistry", by Homer Schwamp, Jr. (Sept. 1989). *The Science Teacher*.
c. "Understanding Dalton's atomic theory", by Walter Erhardt, *The Science Teacher* (Sept.1991).
d.. Stinner, A. and Teichmann, J. (2003). Lord Kelvin and the The-Age-of-the-Earth debate: A dramatization. *Science & Education.* **12**(2): 213-228.
e. "The Invention of the Balloon and the Birth of Chemistry", by Arthur F. Scott, in *Scientific American*, Jan. 1984.
f. "The Lunar Society of Birmingham", by Lord Ritchie Calder, in *Scientific American,* June 1982.
g. "Charles Darwin", by Loren C. Eiseley, in *Scientific American,* Febr. 1956.
"Frances Galton", by James R. Newman, in *Scientific American,* Jan. 1954.
h. "The 'unfinished naturalist' of the Beagle", by Irving Stone, in *New Scientist* , vol. 92, No. 1285 (Dec. 24 1981).

DAY 9:

III. MODERN SCIENCE...

THE STORY OF ELECTRICITY: FROM FRANKLIN TO FARADAY.

The story of electricity, from the Voltaic Cell to Faraday's laws of electrodynamics.
Will be presented by the instructor in room 300.

Franklin's model of static electricity

Volta's experiments with electric batteries.

Faraday's electromagnetic experiments.

James Clerk Maxwell and the unification of electricity and magnetism.

J.J. Thomson's experiment to determine the e/m ratio of the electron.

Central Activities: Franklin's model of electricity is tested by students using electroscopes. Coulomb's experiment discussed. Volta's experiments partially replicated using simple equipment and HCL solution. Simplified demonstrations of Faraday's famous electromagnetic experiments. Using a Teltron deflection tube a simplified version of the Thomson's experiments is given.

1. Text: Mason**,** Chapters 37, 38. Appropriate sections in *Harvard Project Physics.*

2. Other Sources:

a. *Project Physics*, James Rutherford *et al*, Chapters 13-16.
b. "Michael Faraday", by Herbert Kondo, in *Scientific American,* Oct. 1953.
Coulomb's experiment
c. "Ninety Years Around the Atom". New Scientist. Jan. 8. 1987.
d. *Treasury of World Science*.
e. *Great Experiments in Physics*, Shamos.

READING ASSIGNMENTS:

Only assignment 1 and 4 are to be handed in. Assignments 2 and 3 should be prepared for class discussion only.

Reading Assignment 1. (To be handed in). Two students.

The following questions, problems and situations are based on *The Scientific Revolution* , by Herbert Butterfield. In addition, it is assumed that you have access to such books as *A History of the Sciences,* by Stephen F. Mason. Prepare your answers by making notes and have these ready for class discussion.

1. Butterfield closes his introductory remarks with this statement: "It would be interesting to know why Western man, though he started late, soon proved himself to be so much more dynamic than the peoples farther east". Comment briefly.

2. Butterfield implies that the preoccupation with the recovery of the lost learning of ancient Greece and Rome was a *necessary*, but not *sufficient* precondition for scientific progress. One is immediately reminded of the struggle of such outstanding figures as Copernicus, Galileo and Harvey. Copernicus spent a great deal of time mastering Ptolemy's *Almagest,* Galileo had to come to terms with Aristotelian physics before he could go on with his studies in kinematics, and Harvey studied the works of Galen thoroughly before going on with his work on the circulation of the blood. Expand on these statements and suggest other important figures in this period who had to come to terms with the ideas and accomplishments of the ancients before going on.

3. It is arguable that modern science emerged partly from the laboratories of such artist-craftsmen as Albrecht Durer and Leonardo da Vinci: they embarked on interrogating nature directly. Butterfield reminds us, however, that they could not get far "because the modern scientific method had not yet emerged". What do you think Butterfield could have understood by "scientific method"?

4. Butterfield reminds us that the compass, gunpowder, and the printing press were technological inventions that "had not been handed down from classical antiquity". First find out how these were developed or discovered and then briefly discuss in what ways these set the stage for the scientific age.

5. Compare the "sciences" of Frances Bacon (exemplified by the experiments on magnetism by Gilbert) and Galileo. Both men claimed that their work was based on the *inductive method* of discovery. Inspite of this claim they had fundamentally different approaches to the investigation of nature. In what essential features were their approaches different?

6. Many scholars argued that a mere shift of the frame of reference does not necessarily result in a superior description of phenomena. Comment.

7.Compare the astronomies of Ptolemy and Copernicus with respect to the following:

a. The presuppositions they make about the world.
b. The degree of conflict with the teachings of the church.
c. Observational precision of the motion of stars and planets.
d. Scientific validity, as understood in the 16th century.

Reading Assignment 2: (To be prepared for class discussion only)

The following questions, problems and situation are based on GALILEO, an article written by the famous historian of science Bernard Cohen. Prepare your answers and have these notes ready for class discussion.

1. Why does Cohen think that "The example of Galileo provides one of the best possible arguments for the need of a continuing and increasing scholarship in the history of science"? Briefly discuss.

2. The Canadian Galileo-scholar Stillman Drake took up Cohen's challenge and wrote several (five?) articles on Galileo in Scientific American, between 1973 and 1985. Using a Scientific American Index, trace these articles. In addition, point out others that have been published during that time on the science history, especially those that are relevant to this course.

3. Galileo predicted that "the new star", sighted in 1604 would "vanish into obscurity". On what grounds did he decide that what was seen in the sky was "a new star"? Why was this considered "a bold assertion"?

4. Discuss how the development of the telescope helped to "vindicate the Copernican idea".

5. List the observation Galileo made with his telescope. How did these observation place Aristotle's ideas into question?

6. How did these observations confirm Copernicus' ideas?

7. Explain how Galileo's discovery of the phases of Venus challenged the accepted Ptolemaic system.

8. Try to reconstruct the "method" Galileo used in establishing his law of free fall.

9. Give an example of a "thought experiment" relating to free fall. Why are "thought experiments" considered so compelling?

10. Read the paragraph on page 46, beginning with..."Galileo's writings abound...". Compare the views of Cohen with those of conventional textbooks as far as Galileo's method of investigating natural phenomena is concerned.

Reading Assignment 3. (To be prepared for class discussion only).

The following questions, problems and situation are based on Isaac Newton, an article written by the famous historian of science Bernard Cohen. Prepare your answers and have these notes ready for class discussion.

1. Newton graduated from Cambridge University at about the age of 21 and then returned to his home at Woolsthorpe for 18 months. Cohen does not mention that Newton returned to his home to escape the plague, which was ravaging London. At any rate, Cohen claims that these 18 months can be described "as the most fruitful 18 months in all the history of the creative imagination". Cohen attempts to back up this astonishing claim. List Newton's accomplishments during this fruitful period of his life. If you are acquainted with any or all of these elaborate a little.

2. Describe the telescope Galileo invented and compare it to Newton's reflecting telescope.

3. In addition to what Cohen says about Newton's theory and experiments on light try to reconstruct his discoveries and his theory-building of the nature of light. Refer to texts, history books. Look at the appropriate section in Harvard Project Physics.

4. Newton shunned people in his middle age and was by all accounts a cantankerous man. How does Cohen account for this? Look up in another book or article about Newton's personality. Find an account of his feud with Robert Hooke (described in another article by Cohen, suggested in the reading list).

5. Compare Newton's absent-mindedness, as described by Cohen, with stories you have heard about Einstein.

6. There was a great controversy during the 18th century as to who discovered the calculus, Newton or Leibnitz. Look up this debate and discuss it briefly.

7. The story of how the writing of the *Principia*, commonly acknowledged to be the greatest and most influential scientific book ever written, is an interesting one. Retell it.

8. The physics of the Principia (three volumes) literally laid the foundations of our physical science. List these foundations and mention the seemingly disparate phenomena they explained.

9. This questions is for the physicists among us: How did Newton prove that

a sphere acts gravitationally as if all its mass concentrated at its center? Why was this an important proof?

10. Newton worked out the results of his problems by first using the calculus that he invented (actually he called it *fluxions*). He then proceeded to use Euclidean geometry in his published proofs.

a. Why did he do that?

b. Historians of science are agreed that this way of communicating with his readers (other natural philosophers) "set back mathematics and physics in England a hundred years". Comment.

11. After laying the foundations for physics for the next 200 years Newton abandoned the academic life. But he continued speculating about many fundamental issues. Imagine that you could go back in time to about 1712, when Newton was 70 years old, and still, by all accounts very lucid. You are granted an audience with him. How would you respond to his speculations, as a 21. century physicist/scientifically literate person?

12. Compare the poetic homage to Newton by Pope with that of William Wordsworth. What kind of picture of the universe and of science, do you think, did Pope and Wordsworth have?

Reading Assignment 4: (To be handed in). Two students.

The following questions, problems and situations are based *Lavoisier and the Theory of Combustion,* by Homer W. Schwamp and on *The Invention of the Balloon and the Birth of Modern Chemistry* by Arthur F. Scott. Prepare your answers by making notes and have these ready for class discussion,

1. Schwamp claims that "the demonstration in which a jar and a burning candle (p. 61)... is not evidence that oxygen exists or that combustion uses it up. Develop an alternate explanation and comment.

2. Make a list of phenomena that a complete theory of combustion would have to be able to explain. (Remember: you are in the 18. century and have been indoctrinated by the phlogiston theory).

3. Using the phlogiston theory distinguish between *calcination and combustion*. Why was the phlogiston theory here problematic? What leads you to believe that the notions of buoyancy and weight (mass) were not clearly understood?

4. Schwamp reminds us (bottom of p. 63-64) that in magnetic and electric phenomena we deal with the concept of negative, so why is it so strange to consider the possibility of negative masses for gravitational phenomena?

5. Why did it seem natural for chemists to identify "inflammable air" (hydrogen) with phlogiston?

6. Consider the following reactions and explain them in terms of the phlogiston theory:

7. Describe Priestley's experiment with the "red precipitate of mercury", and give an account of the series of experiments Lavoisier performed that led him to speculate that Priestley's new gas was "that part of the atmosphere that was responsible for combustion". How did Priestly explain these results in terms of the phlogiston theory?

8. Briefly discuss Lavosier's ideas about what role heat and light played in combustion.

9. Describe how "inflammable air" (hydrogen) was produced by the ballooneers and speculate on the problems that they must have encountered in producing "inflammable air".

10. What was the approximate buoyant force acting on the balloon that J. Charles devised 1782 (page 126), and later on the one designed in 1783? Work this out using (grade 11) physics.

11. Give a brief account of the history of the phlogiston theory and explain why it had such a stranglehold on chemical practices.

12. Trace the development of the chemistry of gases from Black's discovery of "fixed air" to the discovery of "inflammable air" by Cavendish. How did Cavendish compare the masses (weights) of air and "fixed air"?

13. How did Lavoisier eliminate "earth" as an Aristotelian elementary substance ?

14. How did Priestly improve on the 18. century technique of collecting gases? Give a brief account of his discovery of "dephlogisticated air" (oxygen).

15. The phlogiston theory was not easy to replace. Trusted theories in science are difficult to overthrow (Newton's theory of gravitation, the caloric theory of heat). Scientists invent "protective hypotheses" to defend them (for example, Priestly claimed that phlogiston had a negative mass). What evidence did Lavoisier have to amass in order to finally bring down the phlogiston theory?

16. Compare Cavendish's account of what happens when an electric spark is passed through a mixture of common air and "inflammable air" with Lavoisier's explanation.

17. The connection between the discovery of hydrogen, the chemical revolution, and the development of the balloon is complex. Give your own brief account of it.

UNITS OF HISTORICAL PRESENTATION

The following is a brief outline of what we call "the units of historical presentation" (UHP). This is not an exhaustive list but includes most approaches used in placing science in context and in the presentation of history. All UHP (with the possible exception of vignettes) are designed according to the following format.

(See: Stinner A., McMillan, B., Metz, D., Jilek, J., Klassen, S. (2003). The Renewal of Case Studies in Science Education. *Science & Education* **12**: 617-643.

(Please note that in this course we will concentrate on only two of these, namely, historical contexts and case studies).

1. Historical context*:* the scientific ideas of the historical period are given to show how they are connected to the topic.

2. The experiment(s) and the main ideas: Main ideas and/or empirical support for what is central to the UHP is presented. Demonstrations are suggested and experiments described.

3. Implications for scientific literacy and the teaching of science*:* .

How would one present these concepts/ideas/experiments in the classroom? What are the diverse connections of the concepts under discussion?

Vignettes.

The smallest unit of historical presentation is the *vignette,* developed and discussed in great detail by James Wandersee (1992). He argues that introducing a well-crafted and well-chosen vignette into the classroom connects the concepts and ideas under study with the interests of the student. Vignettes should also "serve as motivation and encouragement for students to read more about science and scientists" (Wandersee, 1992, p. 21). Although these small UHPs are mostly told to arouse interest and create motivation for studying science, they can also make scientific ideas and concepts.

Historical Contexts

Historical contexts are simple stories that engages the interest of the student to do an experiment, discuss the motivation of the scientist or the science described and become acquainted with the historical context of the story. Generally this presentation deals with one unifying idea, designed according to the guidelines given in the table below.

Case Studies.

Case studies are large-scale historical contexts that are generally much more complex and have more diverse connections than the historical contexts. They are on a larger scale, and multidimensional, suitable for senior students.

Confrontations.

We are inclined to think of modern science as having resolved most issues. Quite the contrary is true; science in the 20th century is fraught with confrontations, some completely or partly resolved, and others still raging. Sometimes there are many competing theories seeking to lay the foundations of a new discipline, as in the case of the eighteenth-century science of electricity and Lavoisier's new chemistry and the alchemists, but mostly scientific confrontation is the squaring off between two rival theories.

Thematic narratives.

This approach identifies general themes that transcend the boundaries of individual scientific disciplines and may have interdisciplinary and humanistic connections. For example, the thematic couple of atomism and continuum “played an important role in shaping the conceptual structure of early twentieth-century biology and science” (Jordan, 1989). Other themes could be conservation, time, regularity and evolution. These themes transcend individual disciplines and often link major activities in the various disciplines and touch on humanistic activities. It is often convenient to connect several small case studies to produce a continuous narrative with an underlying theme.

Dialogues.

Galileo used the dialogue format in his books in order to dramatise his science. To make his “new science” more accessible to the general reader he wrote the text in Italian rather than in the conventional Latin. Galileo’s approach has been “rediscovered” by several science educators (Lockhead & Dufresne, 1989; Raman, 1980): “The method I discovered recently was to present the relevant information and ideas in the form of a dialogue in which the original scientists are made to speak of their ideas and theories” (Raman, 1980, p. 580).

Science Drama.

The role of the scientist in society has been a subject for playwrights for hundreds of years, many modern plays have been written about science and scientists in modern society (Brecht: *The Life of Galileo*; Golding: *The Physicists*; Kipphard: *In the Matter of J. Oppenheimer*. Recently the play *Copenhagen* that is essentially a dialogue between Heisenberg and Bohr in 1941 has been playing to capacity audiences in Europe and North America. Jonathan Duveen and Joan Solomon (1994) have written and used such plays as *The Great Evolution Trial* to encourage students to role-play in the classroom.

EXAMPLES OF UHPs:

I. VIGNETTES:

Archimedes and the law of flotation

An early example of a successful *thought experiment.* The original "Eureka" incident in scientific discovery.

Archimedes and the law of the lever

“Give me place and I can lift the world”

Archimedes and the law of reflection

“I can destroy the ships of the enemy by reflecting light unto their sails”.

Aristotle experiment: "The embryology of the chick".

An early example of keen observation in biology.

Zeno's paradox of the hair and the tortoise

“Motion is impossible”.

Archimedes' war machines.

He was a theoretician who delighted in making technological devices.

Galileo and the Cardinal

"I will not look through this instrument of the devil"

Galileo and the Tower of Pisa.

Not considered a true story but still fun to tell.

Newton and the apple tree.

Newton himself tells the story about what led him to his early calculations of the orbit of the moon. But did it really happen as he tells it?

Count Rumford and the boring of canons

"Heat is produced by work and not by liberating the caloric fluid"

Dr. Doppler's demonstrates his theory

Musicians on a railroad car (1841) demonstrate the Doppler effect in Vienna.

Kekule: ***The Benzene Ring.***

"...Then one of the snakes seized its own tail".

II. HISTORICAL CONTEXTS

Examples of Greek Science Theories:

Empodocles' theory of evolution

Democritus' atomic theory of matter.

Anaxagoras' theories about the origin of the universe

Archimedes: ***The discovery of the law of flotation.***

Quantitative discussion of Hero's crown problem**.**

The three outstanding mathematical problems of the Greeks:

The squaring of the circle, the trisecting the angle, and the *Delian* problem.

Eratosthenes of Alexandria: ***The measurements of the radius of the earth.***

The first successful "measurement" of the dimensions of the earth and the solar system..

Greek technology and inventions:

Archimedes' screw

Hero's steam engine

Hero's experiments

A water clock

The Ptolemaic solar system

How can we save the phenomena? The ugly motion of retrograde action can be explained using epicycles.

Erathostenes and the size of the earth.

The shadow cast on summer solstice in two different places allows the calculation of the size of the earth.

Aristarchus of Samos the determination of the distance to the sun.

The distance to the sun can be calculated in terms of the distance to the moon

Toricelli: ***Finding the weight of the atmosphere.***

A triumph of scientific imagination.

Galileo and the *discovery of free fall.*:

He knew what the law of descent had to be, even before he experimented with the inclined plane.

Copernicus: *The sun-centered solar system.*

The paradigmatic example of a *gestalt- switch* in scientific thinking.

Aristotelians' objections to Copernicus' theory of the heavens.

Aristotle's physics fails to provide counterarguments to the claims of Copernicus.

William Gilbert and the magnetic field of the earth.

The earth is a giant magnet

Harvey: *The motion of the heart and blood of animals.*

The first *thought experiment* in biology.

Kepler's laws of planetary motion.

He used Tycho's observations and 18 years of struggling to find "harmony" in the numbers. He was looking for harmony in geometry as well as in

algebraic representation.

Galileo and his telescope: "The Starry Messenger".

There are mountains on the moon and there is another "solar system": A vindication of Copernicus.

Galileo's inclined plane experiment.

To find the equations of motion in free fall "diluted" gravity.

Robert Boyle and the *measurement of the spring of the air:*

The law emerged from the measurements.

Robert Hooke and the microscope.

His book *Micrographia* caused a sensation**.**

One day in the life of Robert Hooke, the secretary of the *Royal Society.*

He was the British Leonardo da Vinci.

"A day in the life of an alchemist".

The strange world of the alchemist, in the quest to change lead to gold.

Newton's laws of motion.

The motions of the moon, the tides and the pendulum were all explained.

Roemer: *The speed of light.*

He answered the question: "Is the speed of light finite or infinite"?

Stephen Hales and *the circulation of sap in plants*:

Deciding between rival theories.

Jenner: Vaccination.

. "…the boy spent the night with some degree of restlessness, but on the day following he was perfectly well".

James Watt and *the discovery of latent heat in steam:*

Pure versus applied science

The experiment that upset the phlogiston theory of combustion:

The production and testing for the presence of carbon dioxide,

hydrogen and oxygen

Joseph Black and the theory of latent heat.

Every substance has an assignable k specific heat.

Biology in the eighteenth century.

Linnaeus replaces the Aristotelian classification system in biology.

Count Rumford and his caloric theory of heat.

"The caloric fluid does not exist, heat is the manifestation of the motion of atoms**".**

Coulomb's experiment

The inverse square law of gravity must also apply to electric forces.

Oersted's experiment.

One of the great discoveries in science that was made in the lecture hall, in front of students.

Faraday's electromagnetic experiments.

His famous E-M rotation demonstration and his experiment that lead to the discovery of electromagnetic induction.

Faraday's electrochemical experiments.

Underlying chemical reaction is electricity. Is there a smallest unit of charge?

Joule's experiment.

Finding the mechanical equivalent of heat: Count Rumford is vindicated.

Gregor Johann Mendel and *experiments in plant-hybridization:*

Biology as seen through the eyes of a mathematician: A case of premature scientific discovery.

Michelson and Morley and *the impossibility of detecting the motion of the earth:*

There is no evidence for the existence of an *ether.*

III. CASE STUDIES

Aristotle's Philosophy of Science:

"It is not enough to know a scientific fact, you must also know why it is a scientific fact".

We understand through imaginative inductive reasoning from phenomena to principles and then argue from theseprinciples by deductive reasoning back to explaining phenomena

Plato's cosmological question:

"By the assumption of what uniform and ordered motions can the apparent motions of the planets be accounted for? How was this question answered?

Aristotle's biological studies.

His biology and classification endured for almost 2000 years.

Hippocrates and medical science.

The “father” of modern medicine. Discuss the art of science of medicine in his time**.**

!Hyparchus and astronomy

Ptolemy’s astronomy**.**

Medieval Optics. and theory of light

The optical experiments of Theodoric of Freibourg, especially the experiment to discover the "Causes of the Rainbow".

Could medieval physicists have developed a telescope?

The Physics of Motion in the Middle ages:

Nicolas Oresme and the concept of *impetus* in the theory of motion.

Merton and the application of the *mean value theorem* to problems involving average value. How much was Galileo in debt to these natural philosophers for his physics of motion?

Science and Religion in the Middle Ages

Thomas Aquinus and the reconciliation of the bible with the physics and logic of Aristotle.

Leonardo da Vinci’s Science and Technology.

Was he part of the scientific revolution?

The development of modern chemistry from Lavoisier and Dalton, to Davy and Berzelius.

The problem of notation and nomenclature in chemistry.

Count Rumfords experiments in heat and radiation. Rumford performed many ingenious experiments in heat and radiation.

John Dalton and *the atomic theory*:

Wrong assumptions sometimes lead to correct conclusions.

From "The Voyage of the Beagle" to the theory of evolution.

Most of the ideas for his theory of evolution were formed during this voyage.

The story of the law of conservation of energy.

Trace the idea of the conservation of energy from the continental physicists (Leibnitz, Lagrange) to the early chemists (Lavoisier, Dalton) to the physiologists and chemists of the early 19th century (Robert Mayer, Friedrich Mohr) to Faraday and Joule, and finally to the German physicist Helmholz, who is generally credited with the final synthesis in 1848.

The study of electricity from the Voltaic cell to Faraday's laws of electrodynamics.

The basis of Maxwell's great synthesis of electricity and magnetism were laid down.

The discovery of infrared and ultraviolet light: William Herschel and Ritter.

These discoveries are the forerunners of the theory of light and spectroscopy later (1850-) developed by Kirchhoff and Bunsen. Demonstrations required.

The Doppler effect and its use in physics, technology and astronomy.

The vignette of the Doppler effect can be extended to a full-scale case study

Because of the importance of this effect in terrestrial and astronomical applications.

The discovery of Neptune: Newton again vindicated.

Why did the discovery of the anomalous behaviour of the motion of Uranus not topple the Newtonian theory of gravitation?

From the caloric heat theory to thermodynamics

Begin by discussing Joseph Black and James Watt who laid the foundations of heat theory in the late 18th century. Give an account of Lavoisier's new chemistry discuss how the caloric theory of heat became central to it. Give an account of Count Rumford and Sadi Carnot' contribution to early thermodynamics and the that refuted the caloric theory of heat and give an account of Sadi Carnot's argument that limits the energy output of any energy transformation device, such as a steam engine and an internal combustion engine. Why are these studies as important to chemistry and biology as they are to physics?

Chemistry, Physics and the discovery of photography.

The story of photography, from the late 18th century till the first photographs taken in the early 1840's. Demonstrations required**.**

The Cell Theory and the question of spontaneous generation of l

Read about the development of the cell theory from the development of the microscope to Pasteur's experiments to show that life cannot be produced from non-living matter. The elegant early experiments of Redi (17th century) and Spallanzano (18th century) that suggested that life only came from life are especially suitable for early science instruction. One or two of Pasteur's experiments to show that life can only come from life (that cells can only arise from pre-existing cells) may also be suitable to early inclusion in science education.

William Thomson (Lord Kelvin) and *the dissipation of energy:*

A curious interaction between physics, mathematics, geology, biology, and theology. The fascinating story of Lord Kelvin's debate with the geologists about the age of the earth. The debate is interesting because 1. it involved 'non-scientific ideas' and 2. the argument was 'premature' since nuclear energy had not yet been discovered.

Louis Pasteur and *the preparation of artificial vaccines:*
"Luck favours the prepared mind".

IV. CONFRONTATIONS

Galileo and the Church.

The story of confrontation between science and theology

The wave-particle confrontation of light: from Newton to Thomas Young.

Is light a wave or a particle? This question over 200 years to settle, only to be re-opened by quantum mechanics.

Theconfrontation between the phlogiston theorists and Lavoisier's new chemistry.

Combustion involves the taking in of oxygen and not the giving off of phlogiston**.**

Volta and Galvani: The confrontation between the electric theories of a biologist and a physicist.

This confrontation leads to the discovery of the voltaic cell, the first battery that produced an electric current.

V. DIALOGUES:

Copernicus and the Aristotelians

A creationist confronts an evolutionist

Priestley and Lavoisier discuss the relative merits of phlogiston and oxygen theories in explaining combustion and 'calcination'.

VI. THEMATIC NARRATIVES:

The story of force: from Aristotle to Einstein.

See my article with the same title

The story of light: from the Greeks to quantum mechanics

The wave-particle confrontation of light: from the Greeks to the medieval scholars, to the confrontation between Newton's corpuscular theory and Huygen's wave theory, to the reemerging of the wave theory due to Young's experiments (1806), and finally to modern quantum theory (Planck, 1900) and Einstein's photoelectric effect (1905).

This confrontation turns into the idea of *wave-particle duality* when quantum mechanics emerges.

A simple mechanical model will be discussed to illustrate Newton's particle model of light. Using single and double slits on smoked glass students test Young' interference formula. Young's experiment to demonstrate the wave nature of light. Determining the wave length of a He-Ne Laser. Photoelectric effect demonstrated. Identification of gases using a simple spectroscope.

The idea of the atom: from Democritus to Bohr.

The story of the concept of the atom from the Greeks to Dalton. Why was it not possible operationalize this important concept until the time of Dalton?

The study of electricity from the Voltaic cell to Faraday's laws of electrodynamics.

Include Oersted, Ohm, Ampere, and Faraday. Discuss the important experiments that led to such concepts as electro-magnetic induction and the development of such technological devices as the electric motor

SCIENCE DRAMAS:

The Trial of Galileo

This famous trial should be scripted and presented to the class.

The public debate between science and the Church of England: Darwin (actually, his "bulldog" Huxley) confronts Bishop Wilberforce.

This famous trial should be scripted and presented to the class.

The Age-of-the-Earth debate.

A debate set in 1872, with Kelvin, Huxley, Lyell, and Helmholtz representing the disciplines of physics, biology, geology, and cosmology). This play was performed at the Deutsches Museum in December of 2000 and shown on Bavarian TV. See my article.

Count Rumford.

This play tries to capture the complex personality of Count Rumford, in four scenes. scenes. The participants are Count Rumford, Madame Lavoisier, Pierre Laplace, and Sir Humphrey Davy. The first scene is set in 1781, in Massachusetts, in the American Colonies. The second scene in London, in 1783. The third scene is located in Munich, in 1792, and the last scene in Paris in 1805. This play was performed in German at the Deutsches Museum in Munich in December of 2002 and again at the University of Winnipeg in 2005.

An Evening with Einstein and Sir Isaac Newton.

This play was performed at the Deutsches Museum in Munich in October of 2005 (in celebration of the "Einstein Year") and again at the International History and Philosophy of Science Teaching (IHPST) conference in Calgary in July of 2007. The play takes place in Albert Einstein's house, 112 Mercer Street, in Princeton, in March of 1955, just a few days after his 76th birthday, and two weeks before his death. The participants are Albert Einstein, and Sir Isaac Newton

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NOTES: