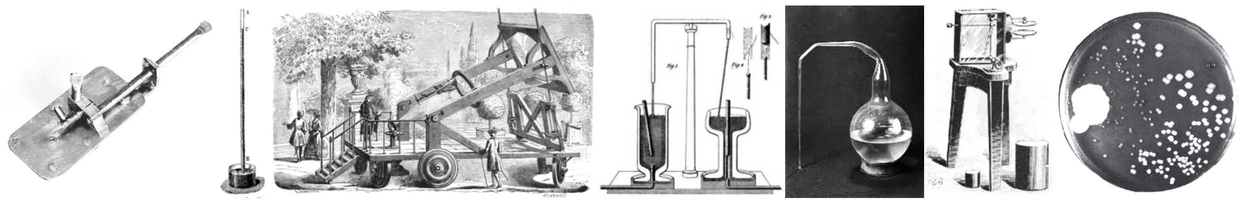

"What is good education? Giving systematically opportunity to the student to discover things by himself." George Polya

Great Experiments That Changed Our World
Syllabus 2020

Instructors:

Philip M. Sadler, Ed.D., psadler@cfa.harvard.edu
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Obs. D-315, 617-496-4709;
Office hours, Tuesday 3:30-5:30

Max Mulhern, Head Teaching Fellow

Theron Carmichael, Teaching Fellow, Graduate Student in Astrophysics

Fred Shipley, Teaching Fellow, Graduate Student in Biophysics

Time and location:

Tuesday, Lecture/Lab, 9:00-11:45AM
Thursday, 1-hour section for :reading discussion and problem set help, 9:00-11:45AM
Science Center 106

Course Description

Facing the edifice of preexisting knowledge, how are breakthrough discoveries made that contradict the existing scientific canon? Twelve great experiments that have transformed our understanding of nature will guide us, first through immersion in the scholarship and popular beliefs of the time. Next, how did the discoverer prepare? What were the motivations, prior experiences, and training that led to the threshold of a fruitful advance? Then, to the degree possible, we will carry out the exact same investigations, building our own simple equipment from scratch, duplicating the challenges of wresting patterns from noisy and incomplete data. Students will compare their results to both private and published versions of the original research. The course will examine the magnitude of the cognitive shifts experienced and the often-uphill battle to acceptance. We will build an understanding of the nature of scientific progress, examining how the mastery of natural phenomena leads to new technologies and how these can contribute to further scientific discovery.

Experiments are drawn from the natural sciences, ancient to modern, from Eratosthenes measuring the earth's size to Rosalind Franklin determining the structure of DNA. We will consider what constitutes beauty in science and how these discoveries continue to impact society, as well as the many ethical questions raised. The course will examine the difficulty of accepting new experimental evidence falsifying accepted scientific paradigms and how this remains an issue playing out in current society. By unpacking these 12 experiments, students will be able to better prepare for their own future discoveries and contributions in fields which they choose to study, whether in or outside the sciences.

Course goals are derived from several fields of inquiry:

1. Scientific: Carrying out experiments using simple materials, as close to the original methods as possible. This includes construction of some simple equipment and instruments (e.g., making a simple microscope in order to be able to see microorganisms, as von Leeuwenhoek did).
2. Historical: Reading original sources to understand the accepted scientific paradigm prior to the discovery, the seminal experimental paper, the follow-on discoveries and their formalization (e.g., the phlogiston competing with Lavoisier's theory of combustion and its application to modern chemistry).
3. Philosophical: How discovery illustrates the underlying processes of science, the value of science's unique self-correcting nature, and how science differs from other ways of knowing (e.g., the interplay of experiments and theory: how Hertz's discovery of radio waves resulted from Maxwell's theory which, in turn, was the formalization of Faraday's experimental discoveries)
4. Cognitive: the self-preparation undertaken by the key scientist(s), their notes concerning their attempts to understand their findings and recognize their implications, relevant similarities to the ways in which learners often go through the same cognitive changes (von Helmont's explanation for the increase in weight of a willow tree)
5. Technological: How control over scientific phenomena results in new technologies that impact human problems. (e.g., Fraunhofer's use of absorption lines in the solar spectrum to solve the problem of chromatic aberration, improving optical instruments used in all scientific fields, the military, photography, etc.).
6. Sociological: how scientific discoveries and their technological application have changed society, for good and bad. (e.g., the discovery of penicillin by Fleming and their wide distribution both saving lives and giving rise to antibiotic-resistant organisms)
7. Ethical: Of what value is science to society? What are the responsibilities of scientists and non-scientists in limiting scientific experimentation? How should these decisions be made, if at all? (e.g., decisions concerning the genetic modification of organisms)
8. Haptic: Developing capacity to build and troubleshoot instruments and experimental artifacts to manipulate natural phenomena and systems.

Current List of Experiments:

#	Experiment	Focusing Question	Scientist(s)	Year
1	Pendulum isochronicity	What is so special about the pendulum?	Galileo Galilei	1602
2	Size of the Earth	How do you measure the circumference of the earth without leaving home?	Eratosthenes	240BC
3	Discovering Microbial Life	How was microbial life discovered with a microscope costing less than 1 cent?	Antonie van Leeuwenhoek	1673
4	Photosynthesis	Where does a tree's mass come from?	Jan Baptist van Helmont	1640?
5	Antibiotics	How was penicillin discovered?	Alexander Fleming	1928

6	Magnetic compass	How are electricity and magnetism different from each other?	Unknown/Gilbert	1100
7	Electromagnetic Induction	How can electricity and magnetism be made into each other?	Michael Faraday	1832
	Spring Break			
8	Death of Phlogiston	Does heat have weight?	Antoine and Marie-Anne Lavoisier	1772
9	Radio Waves	How are radio wave created and detected?	Maxwell/Hertz	1887
10	Moon/Jupiter	Can $1 worth of lenses see mountains on the moon?	Galileo Galilei	1610
11	Decomposition of light	Can white light be pure?	Isaac Newton	1665
12	Structure of DNA	How can the structure of objects be determined that a microscope cannot see?	Rosalind Franklin	1952

Several aspects of the course’s pedagogy are intended to allow students of vastly different skills, preparation, and interests to engage with the course in a variety of ways. All class sessions are interactive and hands on – with short presentations offered by the instructor and a discussion when new topics are introduced. Each student is explicitly encouraged to follow their unique interests, inspired by those that they expect to pursue in life after college: whether they are recreational, hobbyist, professional, intellectual, historical, military, or involve the teaching of science or mathematics in formal or informal settings.

This is a course without science or math prerequisites. Some memory of high school math and science is all you need, but be prepared to use or, at least, question what you remember. You will build many of your own instruments from scratch. This is not a fact-based course, but one in which concepts are learned from a multitude of approaches and your skills are built to a high level of mastery through a mix of observation, calculation, and theory, with a heavy focus on the practical application of knowledge. Facts can be easily looked up, although memorizing a few key ones rarely hurts. Concepts must be learned and integrated into our knowledge structures, while unproductive conceptions must be unlearned and abandoned. Skills can be acquired through interaction with those who are expert and they must be practiced until mastered. As one student summed up the pedagogical approach of the instructors:

> *“The subject matter is fascinating: the topics added to my understanding of the world I encounter every day. The teaching staff was phenomenal: each instructor brought a different perspective and balanced giving tips with letting students struggle. The students were great: everyone was interested and engaged in the laboratory activities. The field trips were enjoyable and useful: going out to see and into the museums added experiential and historical components to the course. The assignments were thoughtfully constructed.”*

Work Load:

The workload in this course is appropriate for GenEd. A typical week requires:

Lab/Lecture	3 hrs
Reading preparation for labs	1 hrs
Problem set	2 hrs
Journal	1 hr

In addition, over the course of the term you must complete a team project, study for exams, and prepare and present of one oral report.

Student Selection:

This is a laboratory course and enrollment is limited to 50 students. The Gen Ed program will carry out the lottery, if needed.

Grading:

Students receive feedback for most course activities. This is not a course in which you can skip classes with impunity. Every class builds on earlier ones and making up a lab is definitely worth the time. Your final grade in the course is determined by the following weights:

Course Component	Weight	# of each
Attendance/Participation in Weekly Labs	20%	
Oral report	5%	
Weekly problem sets	25%	
Journal	10%	
Term Project	15%	
Final Exam	25%	1

Per university policy, graduate students must complete additional work to obtain graduate credit. This is usually in the form of a short paper that relates a great experiment to their chosen field or generation of a new or improved problem set or lab. These projects must be approved by the instructor. For example, students from the Graduate School of Education have prepared an in-depth critique of the pedagogy of the course with suggestions for improvement.

Collaboration Permitted in Written Work, Problem Sets, and Presentations

For assignments in this course, you may work with teammates in lab and on presentations, but all members should contribute equally. Presentations and labs are expected to be carried out in teams of 4-6. You must also adhere to standard citation practices in this discipline and properly cite any books, articles, websites, lectures, etc. that have helped you with your work. If you received any help with your writing (feedback on drafts, etc.), you must also acknowledge this assistance.

Discussion and the exchange of ideas are essential to this course. For assignments, you are encouraged to consult with your classmates as you work on problem sets. However, make sure that you can work through the problem yourself and ensure that any answers you submit for evaluation are the result of your own efforts. You should not share the text of answers or have others plot on your charts. Each student should write their own answers in their own words. You may utilize other students' journal data in your journal entries and analysis, but you must credit them specifically. Journal data should be the results of your own or your team’s measurements. Data drawn from software, the web, or other sources cannot be passed off as your own observations. All observations are assumed to be yours unless otherwise noted by you in writing. In addition, you must cite any books, articles, websites, lectures, etc. that have helped you with your work using appropriate citation practices. Similarly, you must list the names of students with whom you have collaborated on problem sets.

No Collaboration on Exams

All exams are completed individually. There is no collaboration or sharing allowed on exams. No computer programs or web tools are allowed. Calculators can be used during exams for arithmetic and trig functions (if needed). Take-home exams (if permitted), must be completed without any outside help from classmates or others. Exams are "open book," but no sharing of books is allowed. You must have your own copy of text materials for reference.

Philosophy of this Course

Students who enroll in this course offer a variety of reasons for enrolling. The history of science is of great interest to some and this course draws on Harvard's special status in development of American science. Some plan to have STEM careers and want to know more about the people and processes of science. Others want to build their capacity for understanding the technological world and many of the technologies that we take for granted. Still others see teaching in their future, either as pre-college or college teachers. In teaching a science course drawn from multiple disciplines, a key focus on deepening knowledge so that students will be able to teach others, approaching a particular topic from multiple angles. To do this, this course must deal with your prior beliefs about both the nature of science and particular science concepts. It turns out that all of us have ideas about how the world works based on years of observation and interaction. Many of these ideas, however, fail to help us make accurate predictions. We spend time and effort in this course discussing what our conceptions are, whether they lead to correct predictions or not, and how to modify them if they are problematic. Keeping journals of observations in which you can both make predictions of experimental outcomes is a way to document and reflect on changes in understanding. Since many students who take this course will at some time in their lives have the responsibility to teach someone something, we highlight that "telling" is a particularly ineffective method of teaching, but there are a multitude of methods to more effectively and painlessly to get learning to occur.

Much of class time is spent in interacting with phenomena. Students build and work with the tools of science. Most of the time students work in small groups, cooperating with each other to solve problems that are difficult to solve alone. Those with more knowledge of science can contribute to their teammates' learning. Some students are attracted by the unconventional pedagogy of the course. There is a minimum amount of lecturing. Instead, students learn through a variety of active methods. For students who prefer to put in minimal time and then cram in the requisite knowledge just before exams, this course will be a disappointment. Much will happen in class that cannot be learned by reading alone. The guidance of the course's instructors during class will be valuable in helping students develop the tacit knowledge necessary to reconstruct these great experiments. An important part of the course is learning from other students, in lab, working together in study groups, preparing oral presentations, and making observations. Some say that this kind of course is designed for extroverts or, at least, "extrovert-wannabes."

The class provides field trips to take advantage of Harvard's unique assets. The Historical Instrument Collection possesses thousands of instruments that help illustrate the development of science during the past 400 years. Houghton Library holds first editions of many of the books presenting scientific discoveries.

Preparation for Class

Students should prepare for each class by completing the required reading and answering a few reading questions. The problem set must be submitted prior to class, as results will be discussed.

Labs

The laboratories are the key element in this course. You are expected to attend them all and, if you miss any, make them up during the Thursday section time. The labs are timed and should end punctually.

Labs are usually worked on in teams of 4-6 students. Problems can be broken into manageable pieces and shared among group members, but each student should take their own notes. The purpose of this group learning is that each student will learn more, not less, so it is important that everyone masters the material. It is expected that during the first half of the semester, you will work with one set of partners. You'll get new parts in the second half of the course. In this way, you will have enough knowledge about your classmates to choose (or avoid) partners for your presentations and projects.

Lab sessions usually end with a discussion of the group's findings. We attempt to answer remaining questions and dispel misconceptions. You should plan on always staying for the full duration of the lab time. If you finish early, you can start on the problem set, help another team finish up, or do some other work until the group is ready to meet.

Problem Sets

At the end of each lab, problem sets will be distributed. You have one week to complete it; it must be handed in before the next lab for full credit. Over the following week they will be corrected by the teaching fellows. Only papers that are perfect will receive the highest grade, so you should check them over before submitting them. Grades are assigned on the following basis:

Check plus	Highest quality: organized, correct, insightful
Check	Good work with minor errors or mistakes
Check minus	Many errors, gaps, incomplete
No credit	not submitted or submitted with less than 70% correct

Journals

Students are expected to keep a journal of observations and thoughts about the experiments they conduct. This should be in a small bound or loose-leaf notebook, preferably one that has pages that can be used as graph paper. Make sure you and start entries in the first week. The journal will be examined and feedback given at weekly section meetings. Date all entries. You will be asked to post or include in problem setts item from your journal (a data table, graph, drawing or written explanation or hypothesis). These can be snapped with a camera and inserted electronically or copied and pasted in.

Journals are counted as a separate grade and are required. In the past, those students who invested time and energy in keeping good journals found the course (and the exams) much easier than those who did not keep extensive journals. In addition, there will be at least one question on the mid-term and final examination that can only be answered with information from your journal.

Term Projects

Each student is expected to plan and complete a team "poster" project related to one of the great experiments with several partners. Your team should write a short outline of your proposed project and hand it in on the deadline given in class. Some possibilities for report topics are discussed each week. The instructors have some books and files that might be useful, otherwise you can find the needed materials in the Harvard libraries.

Projects are to be presented in "poster" format in class. This means that you are expected to present your project orally using exhibits, models, diagrams, and graphs that are posted for display. In addition, you should include a short, written abstract of your project and bibliography. Photographs and models should be on display at this time. Grading will take place at this session. The quality of your poster and presentation will be judged on:

Clarity of Presentation,
Conceptual Content,
Poster Quality,
Use of References, and
Organization of Project.

Be aware that projects that are thrown together a few days before the presentation usually do not fare well. Those that have been thought about for a month, required the location and assembly of various resources, and have been completed with enough time for reflection (and shown to your friends for feedback) do quite well. If you start early, you can use your journal to correspond with the instructor for feedback or you can meet with him during class, during office hours, or lunch with him after class. Occasionally students make the mistake of constructing an instrument and think that the project is over. If you choose to build something, the majority of the time you spend should be put into using the device to assess its performance.

Final Exam

There will be an open-book, final exam. It will cover the entire content of the course: problem sets, field trips, journals, class discussions, projects, the readings, and labs.

Academic Integrity

Any material submitted to meet course requirements—homework assignments, papers, projects, examinations—is expected to be a student's own work. Collaboration on studying and on homework assignments is encouraged, but you must ensure that anything submitted is the result of your own work and reflects your own approach to the topic. Students must make note of any collaborators when submitting work.

Accommodations for students with disabilities

Students needing academic adjustments or accommodations because of a documented disability must present their Faculty Letter from the Accessible Education Office (AEO) and speak with the professor by the end of the second week of the term. Failure to do so may result in the Course Head's inability to respond in a timely manner. All discussions will remain confidential, although faculty will contact AEO to discuss appropriate implementation.