BURCH SCIENCE SEMINAR IN LONDON, UNITED KINGDOM

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Summer 2012
6 weeks, mid May – late June

I. INTRODUCTION:

Science education in the standard university curriculum is directed toward training students to become proficient in their discipline and preparing them for further study in a specialized field of inquiry. It didn't used to be that way. Two hundred years ago, scientists were reasonably conversant in a variety of disciplines, but today, the current wealth of knowledge is such that students are forced to focus their studies on their own discipline, so that physics students are exposed to precious little biology, and biology students take only an introductory course in physics. Even so, we all have some fundamental knowledge that spans several fields, or at least know where to look for it. Among these are the mass of the earth, its age, the age of the universe, the fact that the earth's center is composed of liquid iron, or that DNA can be used to identify the relationship among people, animals and plants. Yet, if you ask the average scientist about *how* we know these things, the response may well be embarrassed silence.

The purpose of this Burch science seminar is to look back in time at the critical experiments and theories that form the basis of much of our understanding of the world around us. We will discover that what we know is not based solely on some experiment or observation, but is instead the combination of our observations with theories of how the world works. That is, we all observe that an apple falls from the tree to the ground, but it was the genius of Newton who saw the connection between that commonplace knowledge and the motion of the planets, which then led to his gravitational law. Similarly, countless numbers of people observed the variety of life on earth as well as our ability to breed new strains of dogs, crops, etc. But it was the genius of Darwin to pose the right question that led him to develop his theory of evolution.

The London location is ideal for such a course because of its large number of museums and historical sites associated with the history of science. Among them is Downe House (Charles Darwin's home); the Royal Botanical Society's Kew Gardens, where cutting edge research is carried out on plant DNA; the National Maritime Museum at Greenwich, where John Harrison's famous clocks are displayed along with exhibits on the problem of determining longitude; the Whipple Museum of Science in Cambridge; and the Grant Museum at University College London, where many of Thomas Huxley's specimens collected in the mid 1800's are stored.

In this course, we will not only explore the basis of what we know, but also learn to appreciate the role of creativity in developing new theories. This course is then ultimately about the scientific method.

Program Goals:

The goal of this Burch Field Research Seminar is to develop an appreciation for the role of observation and the development of theories to account for these observations. We will do this in both a historical context, by focusing on several major themes in a variety of scientific disciplines, as well as through an independent study project geared to each student's interest. Students will devote a large part of their time to researching and writing papers and making oral presentations, with the aim of developing expository writing, public speaking, and critical thinking skills. The participation of students from a variety of scientific disciplines (primarily biology, chemistry, geology, and physics) will provide opportunities for helping one another develop a deeper understanding of scientific themes across disciplinary lines.

II. ACADEMICS

This summer program will include two three-credit-hour courses, one primarily lecture based, and the other built around independent research and reading.

1. HNRS 353: How We Know What We Know: The Relationship Between Observation and Theory

Approaches: Historical Analysis

This course will cover three broad topics:

a. Measuring distances from nano-meters to meters to light years – Age of the universe

We are capable of measuring distances directly over only a small range of distances, spanning perhaps from a millimeter to some 100 meters. Outside of these distances, meter sticks become useless. Yet, we have measured the distance between atoms in molecules, which is less than one nanometer (a billionth of a meter) to the distance between stars, measured in light years. In this section, we will look at various methods developed for measuring distances from nano-meters, to meters, hundreds of kilometers, and, finally, astronomical distances. An example is the famous oil experiment of Benjamin Franklin, which when combined with ideas that Langmuir developed some 100 years later, provides us with an excellent measure of the size of atoms. (The interesting fact is that Franklin could have deduced the size of the atom, but failed to ask the right question.) Numerous major efforts were made in the 18^{th} and 19^{th} centuries to measure the size of the earth by triangulation methods. Today, we use a similar method in all GPS devices, which can pinpoint our location on Earth to within a precision of less than 1 meter. Of paramount importance is the availability of accurate clocks. Our ideas about the age of the universe are a natural consequence of advances made in measurement of distances, and the big bang theory about the origin of the universe is derived from that. All of the concepts involved in these topics are ones readily familiar to students who have taken introductory courses in physics or chemistry.

Excursions: National Maritime Museum (Greenwich) and the Whipple Museum of Science (Cambridge).

b. Our changing earth – its age, structure, and size

How do we know the size and mass of the Earth? How do we weigh it? The lovely combination of Newton's gravitational law and Cavendish's experimental measurement of the universal gravitational attraction between two massive objects allows us to calculate the mass of the Earth. The amazing fact is that any high school student can do the calculation, and the measurement of the gravitational constant, G, is now an experiment in any advanced physics laboratory. Information about the Earth's structure comes primarily from the study of earthquakes, which leads directly to the conclusion that the core of the Earth is liquid, that it consists of iron, and, therefore, that it must be at a temperature of about 5000 K. We know all this without ever having seen the center of the Earth, or having taken its temperature. How is this possible? How do we know the temperature of the Earth for the past million years? Finally, we will discuss various methods of dating objects, from tree rings to Carbon-14 dating of wood samples and the use of thermo-luminescence of sediment to date rocks. From these measurements, we know that the Earth's age is about 5 billion years. These topics touch on techniques and theories commonly discussed in chemistry, geology and physics. They also relate directly to the formation of life on Earth and its development through evolution.

Excursion: Stonehenge, with an invited lecture on the dating of the pre-historic site; led by Sam Moorhead, a UNC alumnus and curator at the British Museum.

c. The discovery of DNA and its implication for evolution and DNA testing

The theory of evolution was developed on the basis of relatively few facts, which consisted primarily of descriptions of species observed by Darwin and other naturalists, the relatively meager fossil record, and man's experience in breeding animals. Darwin never understood the mechanism by which living things can change over time. All this changed with the discovery of DNA's structure (by Watson and Crick while working in Cambridge, England) and the discovery of mutations during the replication process. The advent of sequencing the human genome during the past 20 years has made possible DNA testing or profiling, the first use of which was by Alec Jeffreys in 1984 at the University of Leicester, England. Such profiling is now a standard tool in all crime investigations. In our exploration of how this is carried out, we will use ideas from biology, chemistry, and statistics. In addition, DNA testing can be used to trace our lineage back in time in order to identify our common ancestors. A large portion of our efforts in this section will be devoted to the role of DNA and mitochondrial DNA in cell biology and its use in mapping the development of humans, animals, and plants.

Excursions: Downe House (Kent); the Grant Museum, University College London, where many of Thomas Huxley's specimens (important in the development of the theory of evolution) are stored; and Kew Gardens, where Mark Chase, an expert on plant DNA and former professor of biology at UNC, is director of the Jodrell Laboratory.

Learning goals

All scientific understanding is based on a combination of experimental observations or measurements, and models or theories for their interpretation and incorporation into the composite scientific framework. Students will be required to delineate between observations, which are immutable and model free (although they depend upon the experimental apparatus), and theories, which are subject to testing, verification, and refinement. The main text for the course, Bill Bryson's *A Short History of Nearly Everything*—which espouses many theories, but fails to provide many details on the experimental observations—will provide opportunities to search for the experiments that underpin our current theories. Although lectures will explore some of these, students will be required to search the literature, some of it original and available at libraries throughout London, on specific topics. These studies will form the basis of small papers and reports to the class. In this fashion, students will develop the ability to pose critical questions about the meaning of scientific understanding and deepen their appreciation for the scientific method.

Course Structure

The class will meet daily from 9:00-10:15 am for lectures (by the resident director and invited London-based faculty) , student presentations, and discussions. The guest lecturers will be experts in biology (particularly in genetics and DNA analysis) in order to supplement the faculty director's expertise. In addition, the schedule will include at least one weekly excursion to sites such as those noted above. As appropriate, students and the faculty director may also attend lectures at the Royal Institution of Great Britain, a science education center within walking distance of Winston House (a schedule of events for May and June is not yet available.)

Contact hours

The approximate breakdown of hours is as follows:

20 lectures/discussions (75 min each) by the resident director
4 guest lectures/discussions (75 min each) by guest lecturers*
6 class sessions devoted to student presentations/discussions

Total: 30 class sessions, 75 minutes each

5 to 6 half-day excursions

Required Readings

All students will be asked to read Billy Bryson's *A Short History of Nearly Everything* before arriving in London. Since that book does not explain the scientific basis of the topics it covers, students will be required to select and read an additional book that probes more deeply into the three core topics around which the course is built. Options include, but are not limited to, the following:

- *The Journey of Man: A Genetic Odyssey*, by Spencer Wells (2002)
- *The Seven Daughters of Eve*, by Bryan Sykes (2001)
- *Why Evolution Is True*, by Jerry Coyne (2009)
- *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time*, by Dava Sobel (1995)
- *The Reluctant Mr. Darwin: An Intimate Portrait of Charles Darwin and the Making of His Theory of Evolution*, by David Quammen (2006)
- *The Dating Game: One Man's Search for the Age of the Universe*, by Cherry Lewis (2000)
- *Miss Leavitt's Stars*, by George Johnson (2005)
- *Weighing the World: The Quest to Measure the Earth*, by Edwin Danson (2006) *The Georgian Star: How William and Caroline Herschel Revolutionized Our Understanding of the Cosmos*, by Michael Lemonick (2009)
- *Life: A Natural History of the First Four Billion Years of Life on Earth,* by Richard Fortey (1998)
- *The Electric Life of Michael Faraday*, by Alan Hirshfeld (2006)
- *The Age of Wonder: The Romantic Generation and the Discovery of the Beauty and Terror of Science*, by Richard Holmes (2008)

Each student will prepare a 30-minute presentation and 5-page written report on the book that s/he has chosen. In this way, students will benefit from the readings done by their classmates, and all will gain additional experience in expository writing and oral presentation.

Course requirements and evaluation

Students will be required to attend all classes and participate in all excursions. Evaluation will be based on the following criteria:

Class discussion and participation	15%
5-page paper and oral presentation based on selected books	25%
Three written assignments (each 3-5 pages long) *	30%
Final exam (multi-question exam requiring short essays)	30%

* These assignments will be on some aspect of the course's core topics. The faculty director will work with students to identify appropriate areas of investigation and relevant sources. The main purpose of these assignments is to develop library research and expository writing skills.

2. HNRS 396: Independent Study in Biology, Chemistry, Geology, or Physics (3 credits)
Major credit: BIOL 296; CHEM 396; GEOL 390; or PHYS 395

Students will work with a faculty adviser in their major department to identify a topic for investigation. They may choose to pursue some aspect of the previous course's core topics, an interest related to research they have undertaken on campus, or research in preparation for a senior honors thesis. Students will have access to original journal literature and to local libraries, including the University College London Science Library, the British Library, the Science Museum Library and Archives (one of the world's largest repositories for the history of science), and the Wellcome Library (for the history of medicine).

Since students will receive course credit in their major fields of study, all will be required to identify a faculty adviser in their major departments <u>before</u> departing for London. Those advisers will serve as instructors of record for the course (as required by the science departments). They will approve research topics, comment on mid-term student reports, and evaluate final papers. The departments of chemistry, physics, and geology have approved this arrangement. Approval form the department of biology is pending.

Learning Goals

The focus and aim of this course is to develop students' ability to learn independently and make decisions about the direction of their inquiry. Most students, who have taken only traditional lecture courses, have almost no experience in this mode of learning. Yet, it is what we all do, once we graduate from our formal university studies. This independent study course is ideal for students who expect to take on a senior honors project.

The course is designed to help students learn to communicate ideas to colleagues outside their fields of study. Early in the course, students will present their topics and describe the direction of their proposed inquiry. Midway through the program, they will present a talk on their preliminary findings and questions yet to be answered, and at the end of the term, they will present talks based on their final papers. Students will field questions from their peers and the faculty director, thus gaining valuable practice in the art of thinking on one's feet. After each talk, students will meet with the faculty director who will review the strong and weak points of their presentations.

If students choose to pursue research topics they already have underway, their faculty advisors will probably assign them to read 5-10 research articles, all very specialized. The challenge will be to translate ideas from that reading into big-picture concepts that will be of interest to the broader community (the class). If students don't already have a research project underway, they may choose a topic from the list below, or another topic developed in consultation with their faculty advisers. The problem then is the reverse. The big picture is evident, but students will need to delve into the particularities of the science that underpins the topic. Either way, the students will be academically challenged.

Course Structure

Because this is an independent study course, class will not meet every day. The schedule below is based on an assumed enrollment of 12 students (and will be modified according if more students enroll).

Week 1: Students will meet with the faculty director to discuss a statement of the problem to be investigated and an oral presentation to be delivered the following week.

Week 2:   Student talks (15 minutes each) will be presented in the first three days. Students will turn in their 1-2 page abstracts of their projects to both the faculty director and their faculty advisers in their home departments.

Week 3: Students will meet with the faculty director for individual consultations. They will also turn in annotated bibliographies of key sources for their projects to the faculty director and their faculty advisers in their home departments.

Week 4: Students will present their mid-term talks (30 minutes each) and hand in their mid-term reports (4-8 pages) to the faculty director and their faculty advisers in their home departments.

Week 5: Students will meet with the faculty director for individual consultations.

Week 6: Students present their final talks (30 minutes each) and hand in their final project reports (10-15 pages) to the faculty director and their faculty advisers in their home departments.

Sample Topics for independent study (for those students not engaged in an undergraduate research project):

- Where does $E=mc^2$ come from?
- Dark matter: What is it? Why do we need it?
- Measuring the size of stars
- The Transit of Venus experiment
- The Maskelyne Schiehallion experiment
- Can we "see" molecules and what do we mean by "see"?
- How the earth's core generates the earth's magnetic field.
- Deep digs: What have we learned?

- The center of the earth: it's composition and temperature.
- Nuclear Reactors: How do they work, and are they safe?
- How does the eye function, and how did it develop in animals and humans?
- The human genome project and its effect on treating or preventing diseases
- What are fossils and what chemical process converts them into rocks?

Course requirements and evaluation

Students will be required to attend all scheduled classes and meet regularly with the faculty director. Evaluation will be based on the following criteria:

Class participation	10%
Two written assignments	20%
a) Initial statement of the problem to be investigated (1-2 pages)	
b) Mid-term report (4-8 pages)	
Three Oral presentations	30%
a) Initial statement of problem to be investigated	
b) Mid-term oral presentation	
c) Final oral presentation	
Final Report (10-15 pages)	40%

Final grades will be assigned by each individual student's faculty adviser, in consultation with the faculty director.

III. PROGRAM LOGISTICS

a. Local Affiliation

The UNC European Studies Center Winston House on 3 Bedford Square will serve as the program base. Students will have access to a range of libraries, including the University College London Science Library, the British Library, the Science Museum Library and Archives, and the Wellcome Library.

b. Student Housing

Students on the program will live in apartments managed by Acorn Group, a property management company based in Bloomsbury. Students share apartments with one or two other students on the program. All apartments are located in the Bloomsbury area of central London (no more than a 10 minute walk from Winston House) and are fully equipped with all cooking utensils, color television and telephone, and are cleaned weekly.

c. Classroom Space and Student Services

The program will use classroom space at Winston House. Program participants will have access to resources at Winston House, including internet access, copiers and printers, and a library and study area. Additional support is provided by the Winston House manager as needed.

d. Transportation and Communication

Students on this program will receive a weekly travel card for London's tube and buses. All program related travel will use public transportation.

e. Safety and Security

The U.S. State Department has no travel restrictions in place for the United Kingdom. The UK is a politically stable country with modern infrastructure and generally a safe place to visit. However, it shares with the rest of the world the risks of terrorist attacks. Students will receive a comprehensive safety orientation upon arrival and will be advised to stay vigilant as they would in any US city to street crime involving theft and pick-pocketing.

f. Medical Care

Hospitals and doctor's practices in London have very modern facilities and medical equipment. Students will carry international health insurance through HTH Worldwide and will receive information of doctors and clinics in proximity to Winston House upon arrival in London. Students will be advised to bring all prescription medicines with them for the duration of the program.

IV. FACULTY DIRECTOR

Tomas Baer is Kenan Professor of Chemistry at UNC. He has taught courses in first-year chemistry, physical chemistry, and graduate quantum mechanics and chemical dynamics. He has also taught first-year seminars in the past six years on topics ranging from the history of science to the analysis of alternative energy sources. Upon first reading Bill Bryson's book, *A Short History of Nearly Everything*, Professor Baer was inspired to delve more deeply into the question of "how we know what we know." He has presented talks on this topic and is currently in the process of writing a book with this title.

Baer's research deals with photoionization of molecules, mass spectrometry, environmental aerosol science, and chemical kinetics. He has published over 250 scientific papers and is the co-author (with William Hase) of *Unimolecular Reaction Dynamics* (Oxford University Press 1996). He is a Fellow of the American Physical Society and the recipient of a Guggenheim Fellowship the Australia/New Zealand Medal in mass spectroscopy. He has held visiting professorships at the University of Paris and UC-Berkeley, and has served on the advisory board for two synchrotron radiation facilities: the Swiss Light Source (SLS) and the Advanced Light Source (ALS) in Berkeley.

Professor Baer will travel to London for a week during the spring term to finalize arrangements with guest lecturers and to visit libraries, museums, and historic sites related to the program.