Teaching the History of Physics:
An experiment in the perception of historical education

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This report represents the work of a WPI undergraduate student submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review.
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Abstract

This Interactive Qualifying Project sought to introduce educational resources targeting the struggles of experimental physicists as a way of enriching the curriculum of mid-level History of Science courses. We extensively researched historical teaching materials in physics education as well as primary source materials in experimental physics to determine specific areas that would have the greatest impact on student learning and be least likely to overlap existing student knowledge. The materials we developed were tested in HI 2354, History of the Physical Sciences, in C Term 2011.

Executive Summary

Experimental physics is an area dominated by large-scale experiments which dwarf all others in the history of science. These experiments, and the people who worked on them, have left a detailed historical record of the evolution of ideas. We believe that students in many disciplines can benefit from understanding the process scientists have gone through to improve their knowledge of the world. Of the experimental sciences we have selected physics because many people associate physics solely with a theoretical viewpoint. However, this approach could be applied to any number of scientific specialties. In this project, we introduced concepts in ways that are both understandable and memorable by using historical examples to put the development of physics knowledge into a practical context.

In this project we collected instructional materials aimed at undergraduate history courses on the history of the physical sciences. These primary and secondary source materials covered experimental developments in the field of modern physics leading to the modification or disproof
of well-known theories. These materials were selected to integrate with existing teach materials on more conventional topics. The information encourages discussion of the evolution of ideas through the introduction of theories that have been refined through experimental research.

Each selection of materials contained a number of different components. We selected both primary and secondary source readings from authoritative sources. We prepared thought questions to accompany the readings and discussion questions designed to reinforce the material and elicit detailed interpretations. Finally, we wrote both short answer and essay questions designed to assess student understanding both prior to and after the completion of the module.

To test the effectiveness of our instructional materials, we presented one set of materials in an existing WPI course, HI 2354, History of Physical Sciences, taught by Professor David Spanagel. We presented the material in the form of a primary sources workshop and two rounds of at-home reading assignments and group discussions, followed by an assessment in the form of short-answer and an essay question on the final exam.
A Note on Authorship

The work presented in this project was completed by WPI undergraduates Michael Fagan and Matthew Gleason under the advisement of Professor David Spanagel. This document was written solely by Michael Fagan for the purposes of fulfillment of the requirements of the Interactive Qualifying Project. Wherever used, the terms, “we” and “our” refer to work completed by both students, including background and primary source research, development of educational materials, and analysis of the experimental data.
Figure 1: The public perception of science
1 Introduction

What role does the teaching of the history of physics, particularly of those experiments or theories later proven false, play in the understanding of key concepts and attitudes in the history of science? How has the public perception of scientific discovery made students unaware of the way science really happens? Paul Vallett, a PhD student in chemistry with an interest in science education, has effectively portrayed some of the myths about scientific discovery in his cartoon, “Public Perception of Science”, shown in Figure 1.

The purpose of this project was to expose students to historical material we knew students were unlikely to have seen before in an attempt to give student a broader understanding of how the process of increasing scientific knowledge actually occurs. We wanted students to have a better understanding of the twisted, confusing path that actually leads to scientific innovation rather than the direct route most commonly portrayed in history of science courses.

Can we develop a way to teach students about aspects of the history of science which do not directly lead to proven theories in modern scientific thought? Perhaps these experiences can present the history of science in a way which stimulates students to think more critically about experimental practice.
2 Background

2.1 The Historian’s Approach

It is, undoubtedly, one of the serious weaknesses in the training of the American student of Physics, that he so seldom acquires an intimate understanding of the historical developments of the subject.

I, myself, regard such historical perspective as essential to any thorough going grasp of the principles of Physics themselves.

If Dr. Chase’s book can exert any influence in rectifying this situation, he will have made a very worthy contribution to American Science. It is, at least, a wholesome symptom that the need for books of this sort which emphasize the development of the subject, is being felt.

These words, written by experimental physicist Robert Millikan in the forward to Carl Chase’s *A History of Experimental Physics*, suggests the historical precedent behind which we conduct this project [Chase 1932]. The historian of science is uniquely situated to present material which may significantly affect the future track of the field. In the experimental sciences, the historian seeks to inform the reader of a particular experiment, not only in its outcomes but also its process, perhaps including the hardship that the scientist underwent to make his discovery. In order to better understand the historian’s contribution to developments in science, an essential tool is a basic chronology of key events in the history of modern experimental physics.

*A History of Experimental Physics* does an excellent job of addressing seminal moments in experimental physics that had a lasting impact on future work. J. J. Thomson’s and Ernest Rutherford’s atom models [Chase 1932, 114] redefined how physicists looked at the structure of the atom, and used these models to try and figure out how to measure and ultimately split the
atom. Millikan’s oil drop experiments [Chase 1932, 167] revealed the fundamental charge of the
electron. Modern physicists have been able to document fundamental charges and partial
charges of the subatomic particles that make up the atom, and how they directly lead to the
behavior witnessed by Millikan. Finally, the research questions initiated by Albert Michelson
and Edward Morley’s interferometer [Chase 1932, 156] have been actively pursued to the
present day.

Carl Chase is a unique figure in the history of physics. Demonstrating a particular
interest in the exploits of the famous and lesser-known experimentalists, Chase approaches
physics with the perspective that we must learn from our trials, no matter how difficult. An
experimentalist must have an open mind, and be willing to exhaustively substantiate his findings.
Chase’s depiction of Michelson and Morley’s aether drift experiments and the development of
the interferometer helped science clarify and remember their contributions and enlightened
further research in this area.

Peter Galison, Pellegrino University Professor in History of Science and Physics at
Harvard University, presented the discovery of neutral current effects in How Experiments End
[Galison 1987]. As both a physicist and historian, Galison is intimately aware of how scientific
history and scientific discovery are linked. In particular, the particle physics experiments
described in How Experiments End are the direct ancestors of experiments currently being
conducted at research institutions around the world. These experiments are more than simply
monumental in their own time. It is from learning about these experiments that many of the most
important scientific discoveries have descended.
It is the historian’s prerogative to present information subjectively. They are scholars of information, and their analysis helps us to formulate our own opinions of the progress of scientific development. Historical analysis encourages us to rethink existing modalities and form new opinions of historical events. This may reveal new insight into the minds of the history-makers.

It is the analysis of the impact of a particular scientific discovery that differentiates from merely a discussion of its occurrence. The Analytic Spirit is a collection of essays discussing the impact of experimentation across a wide range of scientific disciplines [Woolf, 1981]. Written in honor of Henry Guerlac, a historian of science known for his interest in experimentation, by several of his students, these essays help the reader to understand the evolution of scientific thought as shaped by the scientists and the experiments they carried out. While several reviewers have agreed that the collection as a whole is quite scattered [Knight 1983], several of the essays do deal with specific instances of experimental discoveries and how they changed and were changed by their historical context.

Historians have disagreed as to exactly which concepts in physics are particularly seminal, but in general, they seem to be in agreement about several key events, which we will consider further in our own primary source research. Gerald Holton suggests that the publication of Albert Einstein’s papers on relativity, “appear to have been among the chief events to usher in a transformation in the fundamental concepts of physics.” [Holton and Brush 2001, 407]

2.2 The Physicist’s View

The physicist has a complicated relationship with the tangled history of his own field. In the technical papers and textbooks of the experimental physics discipline lie the records of
thousands of experiments, both successes and failures. However, it is often the role of the experimentalist to question existing information in the search for a more conclusive explanation, free of experimental bias or error. However, nonetheless, historical information creeps into even the most technical of scientific discovery.

A standard technical paper in the experimental physics discipline is structured similar to technical papers in any science or engineering field, and provides a unique outlet for potential historical information. In addition to the methodology, results, and conclusions which encompass the scientist’s own work, he or she must delve into the background and prior work in the specific area of interest. It is here that we find citations of scientific experiments and analysis stretching back decades. Not all information found in the prior work may be particularly conclusive or even supportive. A thorough scientist must cite conflicting work and results as well as those that support or reinforce his conclusions. This allows the technical community to provide discourse on the validity of the scientist’s work.

It is in the course of researching and writing this prior work or background section that a physical scientist may encounter historical information that may change the course of his research, or more likely the way he thinks about and analyzes his research.

2.3 The Use of Stories in Teaching

Stories often are more effective and accessible than arguments and explanations. Most students seem to understand stories better than logical reasoning and arguments. Stories add to cultural literacy, enliven presentations, and expand interests. Stories also allow a strong connection with other fields, relate otherwise esoteric subject matter to the universal problem of living, and increase the possibility students will find the material relevant and interesting.
Stories get students thinking and asking questions. Stories allow students to connect with the material. Often, stories include how people of a certain time thought of the material which is easy to connect to. Such biographical information leads students to think what they would have done in that situation or what should have been done. Stories introduce humanity to subjects that have long been decoupled from their origins in the minds of men. Provide points to jump off from and extend the connection to the story to a connection with the material. Stories in education encourage students to think more broadly about the material being presented and its place in their world.
3 Methodology

3.1 Introduction

Our IQP encompassed two distinct modes of work. Initially, we performed a unique type of background research we are calling a systematic source examination. In a systematic source examination, we looked at a chronological sequence of materials created by a single organization or for a single purpose, such as textbooks or course syllabi. From these materials in the history of science and science education, we tried to determine how the history and practice of scientific experimentation had affected the teaching of science. The second mode of our work addressed testing our hypotheses about the design of educational materials in HI 2354-History of Physical Sciences, a WPI course taught during C term 2011 by Professor David Spanagel. The process of testing prototype educational materials in a formal course setting involved design, implementation, and assessment phases. We constructed a historical argument we wanted students to take away from the materials we presented. We used historical resources and modern scholarship to select primary sources and write discussion and thought questions presented in the course. The final phase of the work involved designing and analyzing assessment materials used to determine how students in the course reacted to our materials.

3.2 Systematic Source Examination

3.2.1 Textbooks

We identified three unique types of source materials that we felt would be extremely relevant to our project goals. In the first source examination, we looked at textbooks published in the physics discipline across a range spanning 1881 through 2010. This is intended to show us what concepts are in the common literature of the field at the time of publication, according to
the authors. Furthermore, we can leverage the wide time-scale of the materials to examine changes and trends in these materials. In particular, we chose multiple editions of several of the texts, in order to see historical trends as evidenced within instructional materials created by a particular set of authors and editors. In addition to the state of the art in physics teaching at the time the textbooks were written, we also looked for any mention of historical concepts or analysis in addition to purely scientific material.

In order to organize and classify the textbooks into historical eras, we divided them into time periods represented by major events in the history of physics. We identified two books published prior to 1921, when Albert Einstein received his Nobel Prize for his work on the Photoelectric Effect and the theory of relativity became frequently accepted. The second division contains a single book published between 1921 and 1945, when the atomic bomb was detonated and practical applications of nuclear research became public knowledge. The majority of our resources (five books) come from the period from 1945 until 2000, when the discovery of the Tau neutrino completed the experimental confirmation of the theoretically-predicted Standard Model of Particles, a key underpinning of particle physics understanding. Finally, the physics world since 2000 has seen the construction of the Large Hadron Collider and further theoretical research into dark matter and the underpinnings of our universe (four books). See Appendix I for further information.

3.2.2 Syllabi

In addition to widely published textbooks, we wanted to examine how advances in scientific discovery had penetrated into actual physics courses taught at a specific university. We consulted with WPI’s Physics Department, which maintains syllabi from every physics course taught since the establishment of the department. Our plan was to examine several
representative syllabi from each decade of material. However, time constraints relating to receiving the material from the Physics Department prevented us from performing this specific source examination. From this material, we hoped to track the movement of new scientific ideas and experimental results from the scientific literature into advanced and ultimately introductory physics courses. We continue to consider this as an interesting and extremely broad source of information for future studies in this area.

3.2.3 Course Descriptions

Our final systematic source examination involved research in WPI’s Special Collections department, examining archived course catalogs dating back to the 1920s. We know that many bleeding-edge or advanced research topics are initially introduced into upper level or specialized courses before they are taught in the mainstream. By examining course descriptions, we hoped to look at when and how particular topics made their way into the WPI physics curriculum. As an obvious example, at the beginning of the 21st century several courses at WPI, including PH1130, cover modern physics topics that did not exist prior to the early 1900s. Due to time and access constraints, we were also unable to fully examine these resources for the data we wanted, so we propose this as another valuable source for future research in this area.

3.3 Course Materials

HI2354, History of the Physical Sciences, is a history course first taught during C-term 2011 as the second in a series of courses in the history of the sciences. Designed to introduce students to the historical underpinnings of the modern sciences, HI2354 gave us an opportunity to examine how the teachings of certain events and attitudes in the history of science would influence student perceptions. Professor David Spanagel, the designer and instructor of the course, also advised this Interactive Qualifying Project, and he suggested that this course could
be a useful venue for examining education in the history of science. The author of this report was also enrolled in the course, and completed an alternate assignment in lieu of the final examination. He provided insight into the actual discussions and overall reception of the course by the participants, particularly of the materials we developed.

3.3.1 Instructional Materials

3.3.1.1 Prepared Readings

For our portion of the class readings used in the course, we wanted to select materials that introduced students to concepts and viewpoints outside of the traditional bounds of a history course. We wanted to select both primary historical sources, as well as critical articles drawn from the history and science literature. For the primary sources workshop, we selected two sources describing new forms of penetrating radiation. The first article, “The N-Rays”, by R. W. Wood, describes the debunking of N-Rays, a fictional form of radiation that was “discovered” by several French scientists in 1903 [Wood 1904]. We asked students to contrast this source with Wilhelm Roentgen’s “On a New Kind of Ray, A Preliminary Communication”, the thorough and systematic revelation of X-rays to the scientific community [Roentgen 1895].

The next set of materials we selected for the students in the course were a pair of at-home readings in preparation for an in-class discussion on the changing scientific climate at the beginning of the 20th century. These pieces were both historical articles analyzing the unique nature of the N-ray phenomenon. Malcolm Ashmore’s piece, published in Social Studies of Science, presented a rather unique viewpoint that was quite different from R. T. Lagemann’s article in the American Journal of Physics [Ashmore 1993; Lagemann 1977]. Finally, for the readings prior to the second in-class discussion, we assigned two chapters from books on the

### 3.3.1.2 Primary Sources Workshop

During a primary sources workshop, pairs of students are assigned two short (typically less than ten pages) primary source documents to read during the class period. After digesting the contents of one’s own document, the pair engages in a conversation that begins by exchanging the information learned from each portion of the primary sources, and then leads into a discussion of questions raised by the documents. The documents are often from different time periods or point of view on an issue, and often the most difficult questions are not how the documents are different but how are they the same. Students don’t write any summaries of the primary sources workshops, but the materials they read often influence their responses to thought and discussion questions as well as potential essay responses to the final exam.

### 3.3.1.3 Thought Questions

Thought questions are supplied to students via the course website to accompany the assigned readings. It is expected that students will consider the thought questions while they are reading and perhaps while drafting their discussion summaries, but they are not mandatory. These questions are general in nature and frequently suggest, but do not restate, questions that may be considered in the in-class discussions. During the course of our project, we wrote thought questions for each of our assigned readings, several of which encompassed general concepts elaborated on in our discussion questions. The thought questions are listed in Appendix III for the Lagemann and Ashmore readings.
3.3.1.4 Discussion Questions

From the prepared readings and primary sources workshop materials, we prepared two sets of discussion questions. Discussion questions are a well-known tool in humanities courses to encourage students to think critically about materials they have read. Discussion questions encourage a deeper thought process than simple comprehension questions. These discussion questions may draw from the reading materials assigned prior to the day of the discussion, primary sources workshop materials, and topics raised during the course lecture. We looked at several sets of discussion questions prepared by the instructor prior to writing our own. The discussion questions comprised two sets of readings, the Ashmore and Lagemann articles, and the Galison and Kargon chapters. The discussion questions we wrote can be found in Appendices III and IV.

3.3.2 Assessment Strategies

3.3.2.1 Experimental Protocol

In accordance with WPI’s Institutional Review Board policies for experimental procedures, we documented and created an experimental protocol covering our assessment of student performance during the course. All students were informed of the general nature of the IQP research on the first day of the course through a section in the syllabus (Appendix II) and by the instructor. No specific opt-out provision was given as students were notified prior to the drop deadline of the course.

All student data was de-identified through the use of unique keys. These keys were used on the pretest and exam booklets for both the midterm and final exams. The index to the keys was held by the instructor and all data was examined for identifying information by the instructor.
prior to viewing by the student researchers. Group discussion summaries were also de-identified prior to publication and distribution to protect student confidentiality. All data was handled in a manner consistent with WPI’s policies for student information.

The experimental protocol as described in this chapter was submitted to WPI’s Institutional Review and on January 14, 2011 was granted Exemption 10-187 according to 45 CFR 46.101(b)(1) for “Research conducted in established or commonly accepted educational settings…” The exemption is shown in Appendix VI.

3.3.2.2 Pretest

At the beginning of the course, the instructor administered a pretest designed to elicit, among other demographic, educational, and experiential characteristics, each student’s historical background and existing familiarity with the development of theory and experimentation in science. Specifically, we wanted to see if students were familiar with theories that had been discredited, or later discovered to be simplifications. In addition to open-ended questions, we also gathered demographic data. In particular, we were interested in prior student experience in history and the physical sciences.

3.3.2.3 Discussion Summary

As a regular part of the course, groups of students hold in-class guided discussions of course readings. They work within the bounds of guiding questions presented to them at the beginning of the class period, but frequently bring up unique and insightful analyses of the reading materials. Following the discussion, one student in each group wrote a discussion summary, a comprehensive record of the arguments made and issues posed during the discussion. Any unique insights brought up during the discussion are likely to be recorded in
this summary. This summary, typically 4-6 pages in length, was posted on the course web portal and was available to all students as a source material for the exams. Discussion summaries represented a substantial portion of the course grade, and we used these documents to gauge the students’ understanding of the source materials that they read as well as the discussion questions we wrote.

### 3.3.2.4 Final Exam

In conjunction with the instructional choices that had been developed in creating the assignments and discussion questions described above, we also developed exam materials to elicit student understanding of the concepts we had presented. We worked with the instructor to formulate several questions which were used on the course final exam. We concentrated primarily on a section of the exam known as Identifications, in which students are presented with several people, concepts, or ideas, and are required to give short answers providing background and supporting material to demonstrate knowledge of the concept. Each exam contains six identifications designed around a common theme, of which students are required to answer four for full credit. The instructor suggested that we decide on the unifying theme and select three concepts drawn from material we presented to the class, and he constructed an additional three from the rest of the course material. For the unifying theme we decided that each identification would be a particular experimental or theoretical concept in the physical sciences, and that students would be required to determine additional information including the basis for the experiment and its outcome. The identifications used on the final exam are found in Appendix V
4 Results

4.1 Lessons about Experimentation in the History of Physics

In Professor Lagemann’s article, “New Light on Old Rays: N-Rays”, he discusses a 70-year-old instance of discredited scientific experimentation. Among other implications, he discusses how nationalistic bias may have significantly influenced the French supporters of N-rays discoverer Rene Blondlot. Particularly at the University of Nancy, a strong sense of academic solidarity did and in some ways continues to obscure obvious mistakes discrediting Blondlot’s discovery [Josef Bolfa, referenced in Lagemann 1977, 283]. This impression is echoed in discussion summaries received from several student groups in HI 2354. “Mostly these experiments persisted due to a combination of nationalistic pride and a sense of denial. Despite the fact that the evidence for N-rays and their overall concept were loose, it seemed like it could be “the next big thing” in natural science. Being forced to deny their existence would have hurt the believers' pride, and strike a blow to their credibility” wrote one team, who demonstrated a solid understanding of Lagemann’s argument in the context of experimentation in physics [Poirier 2011]. They also drew parallels to how in a rapidly advancing field of experimental science, “Blondlot's theories also had a similar reputation of using the latest technology and engineering techniques behind them, which may explain why so many people believed him.”

Malcolm Ashmore’s “The Theatre of the Blind” takes a different approach to the N-rays story. His analysis concentrates on the physicist Robert Wood and his, “rhetoric of undiscovery” which [I] claim lies in his construction and operation of a 'theatre of the blind' in which only we who were not there can see the nothing that is there. Throughout the text, Wood's credibility as a reporter is questioned in the interest of providing a symmetrically
While both Wood’s and Blondlot’s methods are somewhat suspicious, it was the view of one student discussion team that, “Wood had a better scientific approach because being doubtful of the existence of N-rays gave Wood more opportunity to explore what is true and what is not. The general consensus of the group was that Blondlot was not making the efforts he should have been to ensure that his experiments were objective.” [Spetka 2011]

“Theoretical and Experimental Cultures” from Peter Galison’s *How Experiments End* describes the different attitudes in the field of physics with the authority of a scholar who is both a trained physicist and a historian of science. One student team observed, “Mr. LaVerriere [student] stated that one of the main points made was that developing and using apparatuses to experiment with is just as important as creating theories. However, Galison made it a point in his article to say that ‘we must recognize that experimental and theoretical training, skills, and judgments are not necessarily coextensive.’” [Firenze 2011] By recognizing two distinct modes of physic discovery, Galison demonstrates that teaching the history of experimental physics is valuable and unique.

Robert Kargon’s chapter, “Birth Cries of the Elements” in The Analytic Spirit discusses the experimental trials of one specific discovery: the cosmic rays of Robert Millikan. Millikan’s experiments are distinguished by a series of experiments with increasingly more sophisticated instruments and a small cadre of dedicated assistants. “Mr. Owen [student] summarized Millikan’s story by saying that he wanted to disprove entropy by proving cosmic rays existed, but every piece of evidence he found was thrown out due to not enough backing. This actually fits in nicely with [prior analysis], giving a concrete example of how theory affects experiment and vice versa.” [Firenze 2011] Robert Millikan’s dedication to proving theoretical conjectures
through a rigorous experimental regime is one of the stories in experiment physics with which
we determined students ought to become familiar.

4.2 Discussion

We have introduced into a relatively introductory history course a variety of primary
source material we believe represents a unique position in the teaching of the history of physics.
From the surveys we delivered at the beginning of the course, we reached several preliminary
conclusions. Nearly all students had taken at least one basic science course with a vast majority
taking several. Most had also taken at least one history course (See Appendix VII). Most of the
students seem to have at least a rudimentary knowledge of the history of the sciences. Many
referenced fundamental events in science history such as the theory of the heliocentric solar
system, theory of relativity, and atomic and quantum theory. Basic concepts such as these allow
us to compare and contrast them with the more obscure events and primary source documents we
introduced later in the course. Many people refer to Galileo’s proposition of the heliocentric
universe as an example of a theoretical challenge against prevailing theory. Others (though not as
many) reference Einstein’s theory of relativity. We use this explanation to categorize the
Michelson-Morley interferometer experiments. Many people reference the Bohr model of the
atom as a flawed theory or model that was fruitful in stimulating useful experiments and
investigations. This may be due to a slideshow shown at the beginning of class that had a picture
of Bohr’s atomic model. This probably influenced a lot of people. We use this explanation to
categorize the N-Rays experiments. We also asked about famous experiments and observations
in the history of physics and received several relevant responses, including references to the
Michelson-Morley interferometer experiments and Rutherford’s gold foil experiment. We
noticed that Newton’s experience with the apple, a popular misconception, is mentioned by several people as fact.

The final exam allowed us to see how student responses reflected new information they learned as a direct result of the unique materials we had introduced over the 7 week course. Students answered the N-Rays (exam question A) more than any other and the average score on that question was the highest on the exam. This suggests that the story of the N-Rays made a lasting impression. It was the first question most people answered, however, so they may have been answering in order. The interferometer test question was answered the least out of all the questions and those that did answer it did so rather poorly. It seems that many people who answered Essay A drew similar conclusions as to the fluctuating balance between theory and experimentation over time. While many argue that 20th century science became predominantly theoretical others are quick to point out the presence and importance of experimentation throughout this time. Nonetheless, the idea that physics of the 20th century showed a shift in emphasis towards theory is conserved. The exam question encouraged the students to connect 20th century physics with another topic discussed extensively in the course, the history of geology. The canonical example in this area is Alfred Wegener’s theory of continental drift. Several students cited how Wegener’s theory predated the evidence while others argued that it was the evidence that led to acceptance of Wegener’s discredited theory.

Our findings represent the ideas and analysis of a relatively small (N=50) number of students. In particular, since all of the final exam questions were structured to allow students to select any two of three possible essay questions, the sample self-selected to answer our questions based on those which they felt most comfortable. Thus, it is likely that some students elected not
to answer the question related to our materials because they felt uncomfortable or less familiar with that material. The small sample size of our test audience and the lack of a definite control population make it challenging to draw any definite conclusions from our work in a statistical sense.
5 Conclusion

We sought to introduce a type of teaching material consisting of primary source documents on relatively obscure investigations in the physical sciences for the purpose of illuminating the experimental process in the sciences. We contrast this with using similar materials strictly for teaching of lesser-known scientific research. I believe that materials of the type that we introduced, when used properly, have the potential to improve student understanding and provoke thoughtful discussion. In this case, it is very likely that all students in a given course will have had little or no prior experience with the material.

I would conclude that further work in this area would primarily consist of trying to broaden the subject matter and variety of material presented, and locating modern-day primary source material that discusses the impact of the scientific research. It is in this vein that our documents for discussion included both primary sources on the original experiments as well as modern scholarly interpretations.

The results of the systematic source examinations were not nearly as illuminating as we had hoped. Each textbook we looked at predating 1900 had some sections devoted to experimental procedure and one was about experimental procedure entirely. We would suggest that a more exhaustive approach would involve a systematic survey of textbooks and instructional material at a larger or depository library. While requiring significantly more manpower and consume considerable academic resources, it would likely reveal a systematic understanding of the rate at which state of the art discoveries in the experimental and theoretical physics disciplines are incorporated into the mainstream instructional materials. Our investigations of WPI introductory
physics syllabi from the last two decades revealed few innovations in content or delivery. Should this area be explored in future, we would suggest that course descriptions be used rather than syllabi as records of that media have been documented more broadly and offer a more homogenous object of study.

From this project, I learned that selecting and compiling instructional materials is one of the most challenging aspects of the educational process. Even more challenging is designing assessments that effectively clarify student understanding while also encouraging critical thinking and analysis. I found the systematic source examination portion of this project to be extremely interesting, but within the scope and timeline unable to give it due diligence. I believe that from the process of researching the primary source historical literature, I gained significant understanding of some of the problems faced by both experimental physicists as well as historians of science. In conclusion, I would consider this project to be one where while I gained significant experience and we accomplished many objectives, perhaps the fullest potential was not quite reached.
## 6 Appendix I: Systematic Source Evaluation

Distribution of sources by major thematic time periods.

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Appendix II: Syllabus of HI2354, C Term 2011

HI 2354 – History of the Physical Sciences  Term C 2011
Syllabus (1/28/2011)  David I. Spanagel

Introduction: Students should consider this a tool designed for continuous use. It answers many of the questions that will arise during the course of the term. Students should be familiar with all of its contents and should follow instructions in all particulars.

A. Office and Office Hours. David Spanagel’s office is located in Room 239 in Salisbury Labs, his WPI telephone extension is x6403, and his email address is spanagel@wpi.edu. Email is a MUCH BETTER way to communicate than the office phone, which will be virtually useless unless you call during a scheduled office hour. For Term C 2011, his “office hours” are Tuesdays, 10am – 11:50am. Of course, other mutually convenient appointments may be arranged but, given class meeting times and domestic responsibilities, the instructor’s schedule may not be as flexible as the student supposes.

B. Course Objectives. As a 2000-level course, HI 2354 is conceived as an intermediate college-level history survey. As such, its major goals include the development of the reading, analytic (critical thinking), research, and expressive (discussion) skills that students will already have begun to develop during their academic careers at WPI. Students enrolled in HI 2354 will be asked to read and interpret a wide variety of historical materials, to share their interpretations of these analyses with their classmates, and to demonstrate their command of subject matter through examinations and/or research papers. Students completing this course should be able to explain the nature of historical inquiry, to read, comprehend and evaluate primary source materials in the history of chemistry, geology, and physics, and to write effective analytic and interpretive historical prose.

C. The Main Course Topics for C11. During this term the course will examine the history of the physical sciences through a variety of methodological perspectives. Ancient Greek philosophy of matter, a survey of chemical ideas and practices from alchemy to the present, a primary source rendition of the history of physics (by Albert Einstein), popular biographies of James Clerk Maxwell and Niels Bohr, and a journalist’s narrative of the scientific revolution propelled by 20th century seafloor mapping, will each be consulted as we try to understand how and why the physical sciences have changed over the past four+ centuries.

D. Disclaimer for C11. Some experimental teaching materials will be used in certain parts of this class. To determine their effectiveness, a third party study will be performed by an IQP group, whose members will have the opportunity to examine and analyze the content of your responses to corresponding topics on exams and discussion papers. In all such cases, your work will be properly de-identified so no names are released to the study group. By taking this class, you agree to have your work submitted to the IQP study and give the study group the right to excerpt portions of your work for illustrative use in their report.
Requirements:

E. Material to be Purchased. Students should obtain the following five books. Each is available for purchase at the WPI Bookstore. Additional required reading materials will be provided via online links or photocopies.


F. Lectures. Most class meetings will involve at least some lecturing by the instructor, punctuated by relevant questions from and/or brief discussions among the students.

G. Films. Portions of many class meetings will be spent engaged in viewing segments of course related documentary films, followed by instructor-led discussions. Students will be expected to participate fully in discussions.

H. Class participation. Each student’s level of conscientious intellectual engagement while listening, speaking, asking questions – in lectures and especially during review sessions, participating in film debriefings – and otherwise responding to course materials, will contribute 10% to the final course grade.

I. Small group discussions. In five class meetings, the class will break up into 5-person discussion groups to conduct a more intimate and creative discussion of the assigned readings. For every group discussion occasion, one student in each group will take responsibility for recording the entire substance of that group’s work together. These notes will be used by the student to compose a Discussion Paper, which will be graded by the instructor. This paper will also be distributed to the rest of the group’s members (and may be made accessible to the entire class via the myWPI discussion board), to provide everyone with materials for a comprehensive set of notes for the information covered. Discussion Paper responsibilities will rotate within the groups so that everyone will have at least one chance during the term to complete this assignment. The grade on the Discussion Paper will contribute 15% to each student’s final course grade.

J. Exams and optional research papers. Two class meetings will be devoted to written assessments of your learning of the course materials. These will not be intentionally cumulative exams, but all relevant knowledge that you have acquired may be used to respond to the questions. The rules for the exams will permit access to any handwritten or printed out “notes” that students compose for themselves about the lectures, films and readings, plus printouts of
group discussion write-ups. Students may not refer directly to course texts in the exams, nor to any other books, each other’s papers, or any electronic resources whatsoever. The total exam grade will contribute 75% to each student’s final course grade, but the weights of each exam score will be adjusted so that, for each individual, the better exam performance will count for more than the worse exam performance (e.g. 45%, 30%).

Any student may, however, choose to research and write about a specific historical question within the scope of the course, as an extra-credit or exam substitution assignment. All such optional research papers will be due and submitted in a hard copy to the instructor by 12 Noon, Friday, March 4. Students who wish to avail themselves of this option are required to submit paper proposals by 12 noon on Friday, February 11, and are strongly encouraged to submit a complete rough draft of their research papers before 12 noon on Friday, February 25 so that they may receive constructive critical feedback in time to do revisions on their final drafts. Any submitted paper, whose quality exceeds the lower of the two exam grades earned during the term, will be allowed to replace that exam grade in the final course grade calculations.

K. Note on Plagiarism. Not giving proper attribution – and thereby passing off someone else's material or idea as your own - will not be tolerated. All information in any discussion write-up that you work on must have proper attribution of its source, whether it is a quote, a paraphrase, an idea, a concept, a statistic or anything else you got from any source whatsoever, other than your own immediate knowledge. I will insist upon the use of proper historical footnotes or endnotes (as opposed to parenthetic references) for citations from the course readings. I will also urge you strongly to attribute individual ideas brought up in the discussions to their originators. Practice giving your classmates credit for their part in producing a collective body of understanding.

L. Reading Assignments. Students are expected to come to class each day having completed the reading assignment for that day, as outlined in the class schedule (P) below, so that they are optimally prepared to benefit from the lecture and/or participate in the discussions and activities. The heavy responsibility placed on students by WPI’s intense seven-week terms makes this point especially important. Missing class and/or falling behind on the readings are the surest ways to earn an “NR” in the course, because there is virtually no opportunity to catch up on missed work.

M. Students with Disabilities
Students with disabilities who believe that they may need accommodations in this class are encouraged to contact the Disability Services Office (DSO) as soon as possible to ensure that such accommodations are implemented in a timely fashion. The DSO is located in Daniels Hall, (508) 831-5235. All students who require accommodations must schedule a private meeting with the instructor (within the first week of classes if at all possible) to discuss the disability to determine how they can work together to implement accommodations effectively.
Road Map:

N. The Scope of the Field. The history of science is a well-recognized branch of inquiry about the past that concerns itself with interesting and significant questions about humans and their knowledge and beliefs about nature over the past few thousand years. As such, the history of science is neither a branch of science nor a simplified form of “history for scientists.” Instead, historians of science use the tools and methods of historical questioning and analysis to examine details about past scientific ideas and practices that their colleagues and predecessors have worked long and hard to uncover and document.

More importantly, historians of science develop interpretations which call attention to and define the significance of some details over others, culminating in the formulation of fruitful thesis claims that are intended not only to “explain” the past but also to inform further historical investigation. Throughout this process of questioning and analysis, historians of science draw upon and engage the work of scholars who are interested not only in science per se, but its patterns of past interactions with various belief systems, corporations, creativity, culture, economics, engineering principles, aesthetics and the fine arts, the human intellect, influences upon or from literature, things like medical or military applications, political power, technology, and/or virtually any other aspect of human social activity and social structure.

O. The Scope of the Course. It is expected that many students enrolled in this course are pursuing humanities depth in history. This seminar will provide experience in a variety of areas of possible advanced work, showing both how to engage primary historical resources and scholarly secondary literature, skills useful in any field of the humanities and arts.

P. Schedule. This schedule of class meeting topics and assigned readings is, of course, potentially subject to change during the course of the term. It provides, however, a framework that both students and the instructor will find useful as they try to absorb the wealth of material contained in these five distinct course texts and additional materials, within the limitations of a seven-week term.

Dates                Topics and Assigned Readings
Fri. Jan. 14         Introduction to the Course
                      How is history relevant to the physical sciences?
                      What kinds of episodes are you aware of, in which new scientific knowledge arose in the physical sciences?

Tue. Jan. 18         From Alchemy to Early Modern Chemistry and Mechanics; View “Velocity” segment of Einstein’s Big Idea
                      Primary sources workshop on early theories of matter
                      Read before class: Einstein/Infeld, Part I (3-65); and
                      Levere, Introduction and Chapters 1-3 (ix-x, 1-38)

Fri. Jan. 21         Enlightenment Chemistry; View “Mass” segment of Einstein’s Big Idea
                      Group Discussion #1
                      Read before class: Levere, Chapters 4-8 (39-106)
Tue. Jan. 25  Heat, Electricity, Light, and Color; View “”Energy” segment of Einstein’s Big Idea
Primary sources workshop on the nature of light
Read before class: Einstein/Infeld, Part II (69-122); and
Mahon, Intro and Chapters 1-5 (1-68)

Fri. Jan. 28  Pulling Electricity and Magnetism Together; View “Light” segment of Einstein’s Big Idea
Group Discussion #2
Read before class: Mahon, Chapters 6-10 (69-170)

Tue. Feb. 1  19th Century Geometries of Matter
Exam Review Session
Read before class: Levere, Chapters 9-12 (107-164); and
Mahon, Chapters 11-12 (171-185)

Fri. Feb. 4  EXAM #1

Tue. Feb. 8  From Fields to Relativity; View “Confirmation of E=mc²” segment of Einstein’s Big Idea; Primary sources workshop on penetrating radiation
Read before class: Einstein/Infeld, Part III (125-245)

Fri. Feb. 11  Radioactivity Running Amok
Group Discussion #3
Read before class: Ottaviani, Chapters 1-6 (11-116); Malcolm Ashmore, “The Theatre of the Blind: Starring a Promethean Prankster, a Phoney Phenomenon, a Prism, a Pocket, and a Piece of Wood,” Social Studies of Science 23 (1993): 67-103; and
[Optional Paper Proposals Due today]

Tue. Feb. 15  Quantum Mechanics
Primary sources workshop on uncertainty
Read before class: Einstein/Infeld, Part IV (249-297); Ottaviani, Chapters 7-14 (119-273); and
Levere, Chapters 13-14 (165-199)

Fri. Feb. 18  Solid as the Earth; Primary sources workshop on shifting continents
Group Discussion #4
Read before class: Lawrence, “Preface” through “Challenger” (ix-xvii, 1-100)

Tue. Feb. 22  Gathering Evidence
View Drain the Ocean (87 min.)
Read before class: Lawrence, “Titanic Effects” through “Paleomagicians” (101-214)
Fri. Feb. 25  Revolutions in Physical Sciences
  Group Discussion #5; Exam Review Session
Read before class: Lawrence, “Revelation” to the end (215-256);
  Peter Galison, “Theoretical and Experimental Cultures,” How Experiments
  End (1987): 243-262; and
  Harry Woolf, “Birth Cries of the Elements: Theory and Experiment Along
[Optional Paper Rough Drafts Due today – if feedback for revision
  purposes is desired]

Tue. Mar 1  EXAM #2

Fri. Mar 4  No class meeting (attend classes according to your Monday schedule).
  ALL OPTIONAL RESEARCH PAPERS DUE at 12:00 noon
8 Appendix III: Questions: Lagemann and Ashmore Readings

Discussion Questions

What would the alchemists have said about Louis Blondlot’s theories? How would they have responded to Robert Wood’s accusations?
What about Galileo?
What about Isaac Newton?
What about Albert Einstein?
How did these scientists go against the prevailing worldview with their theories? How did the scientific community respond?

What do you think are Lagemann’s reasons for writing about Wood’s exploits 70 years after they happened? What are Ashmore’s motives for defending Blondlot? What did they hope to gain? What role do the N-rays play in the history of science? What historical lessons can you draw from this episode?

What was unique about the scientific climate of the late 19th and early 20th century that allowed new forms of penetrating radiation to be accepted so readily? What innovations in theory, equipment, and experimental practice fostered these discoveries?

What safeguards exist in the scientific community today to prevent another incident like N-rays? How have fixtures of modern science, such as peer reviewed journals, influenced speculation in scientific inquiry?

Why do you think that Blondlot’s theories, flawed though they were, persisted as readily as they did? Discuss the role of bias in the scientific method. Examine both Blondlot’s experimental process as well as recognition by the scientific community.

Thought Questions

What do you think the role of pseudoscience has been in shaping the history of scientific thought?

Consider Ashmore’s point of view. He is taking a very unusual, perhaps extremist viewpoint on this topic. Would you consider this strange in a modern scientist? Can you think of any other examples of this type of analysis?

What steps did Roentgen, Becquerel, and the Curies take to ensure that their results were valid?
Physics experiments and experimentalists gradually moved from the individual laboratory to collaborative research projects in the 20th century.

- What do you think was happening politically and scientifically that led to this movement?
- How does Peter Galison portray the experimentalists? Has the scientific community given them the recognition they deserve?
- What divides theory and experimentation in science? How are they related, according to Galison? Based on everything we have read this term, is this a relationship that has changed over time?
- Historian Robert Kargon discusses Robert Millikan’s research into cosmic rays and the link between his experimental findings and their theoretical underpinnings. Millikan himself believed there was no such link. What does Kargon believe and why is this significant for the issues discussed in the preceding bullets of this question?
- What were some of the far-reaching effects of the Bohr Model of the atom in the physical sciences? According to Kargon, how did this model affect the path of Millikan’s research?
- In sum, how has our study of the history of scientific ideas and practices changed (if at all) how you think about the validity, necessity, transparency, and longevity of physical science knowledge and practices that predominate in the world today?
10 Appendix V: Final Exam Questions

HI 2354 History of the Physical Sciences
Prof. Spanagel, C11

Name _______________________________ Score ___________ (out of 30)

De-identification code     __ __ __ __ __ Please write this code only on your blue book(s).

Examination #2

Instructions: This is an open notes exam. You may have a writing implement, your class and reading notes, printouts of group discussion write-ups, and this exam before you. Please do not consult each other, the class texts, photocopies of any other readings or printed primary source materials, or any electronic devices. Raise your hand if have a question or if you need an additional exam booklet. When you finish, please give your completed examination to me before you leave. Be as detailed and as factual as you can, in your answers to the questions. You have 110 minutes to work. Good luck!

Part II. Identifying and contextualizing. (Each question is worth one point.) Choose to answer four of the following six questions listed in this part. For each item that you choose, write a short paragraph (of two or three complete sentences) in your exam booklet, which addresses all of the following: Describe what theory or phenomenon this apparatus/expedition was supposed to test. Indicate roughly when (in which decade) and where (in what country/part of the world) the experiment was conducted. Finally, in each case, did the experimental apparatus/expedition ultimately validate or disprove the proposed theory or phenomenon that was in question?

9. Blondlot’s hot wire, iron tube, calcium sulfide thread, and 60° refracting prism
10. The Challenger’s soundings data and dredging observations
11. Eddington’s solar eclipse observations
12. Mason and Raff’s magnetometer measurements
13. Michelson and Morley’s interferometer tests
14. Millikan and Cameron’s high altitude balloon and lake water electroscope tests
Part III. Essays. (Each essay is worth seven points.) Choose two of the following three tasks:

A. Write a detailed 4-5 paragraph essay in your exam booklet discussing the pattern of interactions between theory and experimentation in the 20th century physical sciences. Be sure to indicate specific pieces of evidence to support your claims.

- As a starting point, let me remind you of a quote from the last reading assignment in Transforming Matter before Exam 1: “[Late 19th century chemists Ostwald, Arrhenius and Van’t Hoff] were not only powerful figures in the early days of physical chemistry as a discipline; they also changed the balance between experiment and theory – ideas were now developed and then tested in the laboratory, rather than worked out in the laboratory before being codified in theory.” [Levere, 162]. Was this “new pattern” (theory taking precedence over experimentation) in chemistry also seen in both physics and geology in the 20th century, or were the patterns of interaction between theory and experiment different for these fields?

- Use a detailed example drawn from the Ottaviani book on Niels Bohr’s life and work, to show how theory and experiment seemed to interact for 20th century particle physicists.

- Include evidence drawn from at least one of the supplemental readings (the articles by Ashmore, Lagemann, Galison, and Kargon) to support or contradict Ottaviani’s view.

- Use a detailed example from the Lawrence book on ocean floor mapping to show how theory and experiment seemed to interact for 20th century marine geologists.

B. Write a detailed 4-5 paragraph essay in your exam booklet in which analyze the range of narrative approaches that four of our required texts took to writing about the history of science. Be sure to indicate specific pieces of evidence to support your claims.

- Characterize the Einstein/Infeld book, the Levere book, the Ottaviani book, and the Lawrence book, each in terms of their style of writing and mode of historical argumentation.

- What kinds of historical evidence were most prevalent in each book?

- How did each book balance its focus on people (personalities), places (where work occurred), and specific (chronological) events in its treatment of the history of science?

- Which would you say, of the four, struck the most effective and informative balance?

C. Write a detailed 4-5 paragraph essay in your exam booklet in which you compare and contrast what you know about the life stories of Alfred Wegener and Lise Meitner. Be sure to indicate specific pieces of evidence to support your claims.

- Give detailed descriptions of their career trajectories, the broad range of their scientific activities, and the ways in which each developed an original theoretical insight that radically altered some particular domain within the physical sciences.

- What were the advantages and disadvantages experienced by each of these people? To what degree was each scientist able to carry forward a sustained program of research to follow up on the scientific breakthroughs to which he or she had contributed?

- What broader lessons do these two individuals’ life stories have to teach us about the relationships among German science, society, politics, and religion in the 20th century?
11 Appendix VI: WPI IRB Exemption

WPI

Worcester Polytechnic Institute IRB #1
IRB 00007374

100 Institute Road
Worcester, MA 01609

14 January 2011
File: 10-167


Dear Prof. Spanagel,

The WPI Institutional Review Committee (IRB) has reviewed the materials submitted in regards to the above mentioned study and has determined that this research is exempt from further IRB review and supervision under 45 CFR 46.101(b)(1). “Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.”

This exemption covers any research and data collected under your protocol from 14 January 2011 to 13 January 2012, unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific exemption must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue.

Please contact the undersigned if you have any questions about the terms of this exemption.

Thank you for your cooperation with the WPI IRB.

Sincerely,

Kent Riemmill
WPI IRB Chair
## Appendix VII: Initial Course Survey Results: Course Background

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13 Bibliography


