**Development of Ideas in Physical Science**
**15:256:551 (section 1)**
**3 Credits**

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| Instructor: Eugenia Etkina | Eugenia.etkia@gse.rutgers.edu |
| Phone Number 732 932 7496 ext 8339 | 10 Seminar Pl Rm 217 |
| Office Hours: by appointment | Prerequisites or other limitations: |
| Mode of Instruction:<br>___ Lecture<br>__X_ Seminar<br>___ Hybrid<br>___ Online<br>___ Other | Permission required:<br>__ No<br>_X_Yes<br>Directions about where to get permission numbers: from the instructor |

**Learning goals**

1. To understand how scientists devised the ideas and relations that constitute the content of a high school physics course.
2. To learn how to use a similar process in a classroom to help students construct physics concepts and relations.
3. To learn how to communicate physics process and content in writing.
4. To learn how student learning of physics/physical science relates to the scientists' learning.
5. To experience what it means to design and implement classroom instruction.

**Course catalogue description[1]**

One of the goals of the course is to acquaint prospective and in-service physics and chemistry teachers with the epistemology of physical science and its implications to science instruction. Epistemology is the study of the construction of knowledge. Basically in this course you will learn how scientists know what they know, how they approach problems and how they decide what to keep and what to discard. We will focus on the process that lead to the laws of physics and chemistry that we teach our students and how learning of our students sometimes resembles that of real scientists. You will learn how to use the knowledge of epistemology and history of science to design physics/chemistry lessons.

Another major goal of this course is to help you learn a new approach to teaching and help you start the personal shift from a student to a teacher. Your participation in class discussion, your persistence in the completion of assignments, your creativity and enthusiasm will ultimately determine what kind of teacher you will be two years later. To be the best teacher YOU can be, make sure that you treat your work on each assignment as a step towards this goal not busy class work.

**Class materials**

**Textbooks** required: Gerald Holton & Stephen Brush, Physics, The Human Adventure, Rutgers University Press, 2001. ISBN 0-8135-2908;
Not required but will be helpful: Morris Shamos, Great Experiments in Physics, Dover Publications, New York, 1987. ISBN 0-486-25346-5, available at Eugenia's office for a week at a time.

[1] In this document PTS stands for Professional Teaching Standards, NSCS stands for National Science Content Standards (National Research Council), NJCCCS stands for New Jersey Core Curriculum Content Standards.

**<u>Grading and Activities</u>** Your course final grade will be based on how hard you work: in class, on the homework assignments, on the quizzes, on the analysis of articles, on classroom presentations, and on the design of the instructional materials. **Each assignment can be improved.** I encourage you to try as many times as you need to make the assignment perfect.

During the first week of class, you will take 3 pre-tests on-line (two are physics pre-tests and one is a pedagogy pre-test, please make sure you complete them during the first week).

| **Activity** | **Total points** |
|---|---|
| Attendance, participation | 100 |
| Homework | 100 |
| Quizzes | 100 |
| Interview | 100 |
| NYTimes Project | 100 |
| Storytelling project | 100 |
| History project | 100 |
| Instructional materials | 100 |
| **Grand Total** | **800** |

**Description of activities**

<u>Attendance, participation in class discussions:</u> Class work will be primarily group work. You will explore contemporary versions of classical experiments, read and interpret original papers of scientists, explore how scientists chose one theory over another, and discuss how to adapt some of the historical materials for high school physics instruction. At the same time you will learn how students construct similar concepts. We will also discuss the readings that you will do at home. Each week you will read several of the chapters of the text and additional articles. We will discuss these chapters in class and your grade will depend on you participation in the discussions.

<u>Homework (individual assignment):</u> a) each week **<u>on Wednesday</u>** you will read a chapter/chapters from the textbook describing the development of a particular idea that was discussed in class (see tentative list of topics). Then you will combine the material from class, from the book, and from any other convenient sources (I encourage you to use the Shamos' book and resources on the Web) to write a report reconstructing the inductive, analogical and hypothetico-deductive reasoning and experimental evidence used by scientists to construct a particular idea. In your report try to make a clear distinctions between <u>initial observational experiments</u>, reasoning (<u>hypotheses</u>), <u>predictions of the outcomes</u> of new experiments, based on the hypotheses, and <u>experiments</u> conducted <u>to test</u> hypotheses. Try not to confuse experimental evidence with hypotheses/explanations. Also, do not confuse hypotheses/explanations with predictions. The glossary of terms is at the end of the syllabus. Example: observational experiment (what): You observe that Eugenia has rollerblades in her office.
Hypothesis/explanation (why): Eugenia rollerblades outside during lunchtime.
Prediction (if-and-then): *if* this explanation is correct *and* we call Eugenia's office during lunchtime, *then* she will not pick up the phone.
Testing experiment (outcome): You call Eugenia during lunchtime, she does not pick up the phone.
Judgment: Prediction matches the outcome of the experiment; the hypothesis **is not disproved**. (But it is also NOT proved, as Eugenia could be out for some other reason).

You will e-mail the report with the scores to Eugenia at eugenia.etkina@gse.rutger.edu as a word attachment. Use your first name and the number of the week "Steven5.doc".

***Deadline:*** by **Thursday night** or **Friday before 8 am** you will send the report to Eugenia. Make sure this is the best you can do. On **Friday morning/afternoon** you will receive feedback, and revise the report if necessary by **Monday** morning. At the beginning of the semester BE READY to do 3-4 revisions per homework. Plan your week accordingly so you can spend Wednesdays and Thursdays working on the homework.
During some weeks you will do on-line assignments, be prepared to spend about one additional hour doing those.

Quizzes (individual): At the beginning of each class we will have a short 10-min quiz based on the physics/chemistry ideas that we studies last week. The purpose of the quizzes is to help you focus on the physics ideas, concepts and, most importantly, on the new language that we will be using. The quizzes will be right at the beginning of the class, so please come on time. You can retake each quiz as many times as you need to get it perfect, but all retakes are before class time. If you need to retake the quiz, please come 20 min before class to room 25A. I will be here to give you the quiz.

Interview (individual): As one of the major skills of a teacher is to be able to hear a student, you need to practice listening and hearing. To do this, you will choose one concept whose historical development we will trace in the course and interview two people – an expert in the field of physics and a person who is not familiar with physics. The goal of the interview is to find out what the person understands about the concept and how she/he can apply it. You need to design the interview questions, submit it to Eugenia a week prior to the interview, then conduct the interview, record it and write a report. In the report you need to show that you can connect what you heard during the interview to the history of the development of the concept. The report is due November 1st. Make sure you have enough time for every step.

The New York Times Analysis (individual) Every Tuesday *The New York Times* features *Science Times*. Once a month, you will choose an article from *Science Times* related to physics or chemistry (available on line) to analyze it using your knowledge of scientific epistemology and structural elements of scientific knowledge (observational experiments, patterns, explanatory mechanisms/hypotheses, models, physical quantities and experimental uncertainties, relationships between physical quantities, predictions, additional assumptions, and testing experiments. You will need to type up the article with the annotations on the right side of the page across each statement in the article (see the example attached). By the end of the semester you will need to annotate three articles. When choosing an article try to find one that has a good representation of the elements of the knowledge. You must include the title of the article, its author and her/his affiliation, page number(s), and the date of the article.

History project (group assignment): You will choose one fundamental idea in physical science (from the list in the table below) and trace its historical development following the *ISLE* cycle. You will write a paper describing the development of the idea and prepare a lesson to teach in class in which parts of the historical cycle will be recreated. Use the rubrics for guidance. You will e-mail materials for feedback to Eugenia, revise and then teach a lesson in class. In your lesson you should use at least one experiment that is analogous to a historical experiment important for the development of the idea (or present data from a historical experiment). You should use more than 3 references for the project, Internet materials do not count.
***Deadline:*** 2 weeks prior to class presentation.

Story telling project (individual assignment): You will choose a physicists or a chemist who contributed to the development of your project idea and research personal information about her/him and her/his scientific achievements (you need to find a book dedicated to this person;

Internet materials are not sufficient). You will write a story about her/him that can be told in class while teaching an appropriate lesson. The story should include personal information, information about the historical situation in science, culture and politics, and information about the contribution of this scientist to the development of the idea (or ideas). After you prepare the story, you will e-mail it to Eugenia, receive feedback, revise, and rehearse for oral presentation. Then you will perform the story during class. During the performance you will not read from the prepared document, you will tell the story by heart as an actor.

Instructional materials (group assignment): The story telling project and the lesson curriculum materials **after final revisions** will be copied for all class participants.

**Deadlines:**
Homework is due Thursday night or Friday before 8 a.m.
November 1st – Interview report.
Once a month – your choice – NYT article annotations.
Idea-scientists should be chosen by September 15th.
First draft of the personal story and ISLE cycle is due October 15th.
First draft of the lesson is due two weeks prior to the presentation.
***Final history project materials:*** November 20th.

**Academic integrity: Make sure that you provide proper citations for all materials that you use in your reports.**

**Discussion web board:** Materials for class will be posted on the google discussion board; after you get the e-mail about the posting; you are responsible for printing them and bringing a copy to class.

**Tentative list of topics for discussions and homework assignments (by week)**

| Week | Topic | Assignment (Ch) | PTS | NSCS | NJCCCS |
|---|---|---|---|---|---|
| 1 | Epistemology of physics. Size of Earth | 1, 3, 12, 13, 14 | | A,G. | 5.1 (A, B); 5.2 (A, B) |
| 2 | The study of motion | 6, 7, 8 | | A, B. | 5.1 (A, B); 5.2 (A, B); 5,7 (A) |
| 3 | Newtonian World | 9, 10, 11<br>NY times article | I: iii (1). | A, B, E, F, G. | 5.1 (A, B); 5.2 (A, B); 5.3 (All), 5.4 (A, C); 5,7 (A) |
| 4, 5, 6 | The Laws of Conservation, caloric theory | 15, 16, 17, 18 | I: iii (1) | A, B, F, G. | 5.1 (A, B); 5.2 (A, B); 5.6 (A); 5.7 (B) |
| 7, 8, 9 | Atomic Theory | 19, 20, 21, 22<br>NY times article | | A, B, F, G. | 5.3 (D); 5.6 (B) |
| 10, 11, 12 | Electromagnetism | 24, 25 | VIII: iii (1). | A, B, F, G. | 5.1 (A, B); 5.2 (A, B); 5.4 (all) |

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| 13,14,15 | Light, atom, and nucleus | 23, 26<br>NY times article | VI: iii(1,2), X: ii (3) | A, B, F, G. | |

**Possible Ideas and Scientists for projects (groups of two)**

| Ideas | Scientists |
|---|---|
| Static electricity, electric charge, conductors and insulators | Franklin, Coulomb, DuFay |
| Electron | J. J. Thomson; Millikan, |
| Wave model of light | Young |
| Quantum model of light | Einstein, Lennard |
| Electricity | Ohm, Volta |
| Magnetism | Ampere, Faraday |
| Electromagnetic induction, e/m waves | Faraday, Maxwell, Hertz |
| Particular structure of mater, Laws of Thermodynamics | Dalton, Thompson, count Rumford; Avogadro; Mendeleyev; Boltzmann. |
| Radioactivity | Mari Curie |
| Fission | Liz Meitner |

**The discovery of pulsars**

Prepared by Maria Ruibal-Villasenor, Eugenia Etkina, and David Brookes. The text that is commented below has been adapted from “Little Green Men, White Dwarfs or Pulsars?” by S. Jocelyn Bell Burnell. *Annals of the New York Academy of Science*, vol. 302, pages 685-689, Dec., 1977, and from Cavendish Laboratory Educational Outreach website: www-

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| The discovery of pulsars - rotating neutron stars that generate regular pulses of radiation at their spin rate - was fortuitous. A group of astrophysicists from Cambridge University leaded by Anthony Hewish was looking for quasars (those are extremely bright, compact and remote objects that emit up to a thousand times as much light as our entire galaxy). For that purpose, the research group designed a radio telescope that was built on the flat fields surrounding Cambridge in central England. This telescope did not look like the visible light refractors, also known as dioptrics, which the average person identifies with the word "telescope", long and thin tubes where light passes in a straight line from the front objective lens directly to the eyepiece. By contrast, this radio telescope covered an area of 41/2 acres - an area that would accommodate 57 tennis courts. The radio-telescope consisted of over a thousand posts strung with more than 2000 dipoles between them, and more than 120 miles of wire needed to connect the whole. With the help of university students the researchers built the apparatus themselves, and it took them two years to finish the work. | Originally the researchers were looking for quasars (quasi stellar objects).<br><br>The researchers designed and constructed an apparatus - a radio telescope - to detect quasars.<br><br>The appearance of the telescope is described. There is little explanation of its functioning or how it worked. |
| The astrophysicists were searching for scintillation sources of electromagnetic radiation in the radio range. Scintillation is the apparent fluctuation in intensity of electromagnetic emissions, that is, the apparent 'twinkling' of electromagnetic sources. Most of the sources of radio emissions of the universe are large, such as galaxies or extended regions of gases and dust where new stars are forming. They knew that twinkling of small compact sources is much stronger that scintillation of extended sources. Hence quasars being smaller than galaxies should scintillate more. Radio sources that scintillated a lot were very good candidates for quasars. | The researchers were planning to conduct an **application** experiment: they wanted to **use** their knowledge about scintillating radio sources in order to **find quasars**. |
| Jocelyn Bell, a physics graduate student working on her Ph. D., wa responsible for operating the radio telescope and for analyzing the data, which consisted of nearly 30 meters of chart-generated daily, all of which had to be analyzed by hand. It was better to inspect the data visually to become familiar with the behavior of the telescope and its receivers before designing a computer program. In addition the researchers took into account that people can easily recognize signals of different character whereas it is difficult to program a computer to do so. | Observational experiment - Brief description about what the raw data looked like.<br>A superficial account of the method used for **data analysis**, together with the reason for choosing that method. |

outreach.phy.cam.ac.uk.

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| Two months after the beginning of the experiment, Bell found something strange on the records, a signal that did not resemble other scintillating sources. | Bell collected **unexpected data** that did not fit her schema. The **application** experiment became an **observational** experiment. |
| After more careful analysis of the observations, Bell could determine that the unusual source emitted short pulses with a perfect period of 1 1/3 seconds. Such period is too brief for something as big as a star. | Account of the surprising data: A **pattern** of emission from a source was found. Provides a reason why the **explanation** that the signal originated from star seemed implausible. |
| Hewish believed the pulses to be man-made interference, as with a gap so regular they seemed too precise to be natural. | Hewish's first **explanation** for the odd pulses. |
| The researchers considered a variety of possible explanations for the curious phenomenon, such as: it was a signal reflected from the Moon or emitted by an artificial satellite in an unusual orbit, but they ruled out potential sources of man-made interference one-by-one. It could be that the mysterious signal was created by the telescope itself, however another group of researchers working with a different telescope managed to pick up the same signals, removing instrument malfunction as the possible source of the surprising emission. | A diverse set of plausible **explanations** of the data are generated. **Testing** experiments were designed and conducted to systematically rule out all the explanations. They are not described - probably because the experiments are fairly obvious (e.g., call up NASA and ask them if any satellites are broadcasting on that frequency.) Another **explanation**: the telescope itself created the signal. **Prediction**: If that were true, then other telescopes would not detect the signal. The testing experiment was conducted and the outcome **disproved** the explanation of a malfunctioning telescope. |
| The enigma deepened, Pilkington measured the dispersion of the signal and found that the source was outside the solar system but inside our galaxy. | Pilkington conducted a new **observation** experiment and found that the source of the signal was outside the solar system. |
| It could be that the rapid signal originated from an extraterrestrial intelligence. If the signal was coming from an inhabited planet, and since planets orbit around a star then a Doppler shift effect had to be observable in the radio pulses: the frequency of the radio emission would be higher when the planet was moving towards us and lower when it was moving away. However the researchers only measured changes on the radio frequency were only due to the motion of our own planet around our Sun. The signal continued being a puzzle. | New possible **explanation** that incorporates Pilkington's observation. Reasoning a way to **test** the explanation: measure the Doppler shift. **Assumption**: ET is emitting the signal from a planet, not from some interstellar probe. **Prediction**: If signal is emitted from an extraterrestrial planet, a specific pattern of Doppler shift should be seen. The outcome **ruled out** the explanation. Note that the assumption is left implicit in the description. |
| Bell continued with the analysis or the data produced by the telescope and found three other similar pulsating radio sources at very distant points in the sky. | Additional new **observations**. |

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| These findings excluded the explanation of alien civilizations because it is very unlikely that different groups of intelligent extraterrestrial creatures, extremely far apart from each other, were choosing a similar frequency to send a signal to the same planet, the Earth. | More **observational** evidence that was incompatible with the explanation of an alien civilization. |
| It seemed highly improbable that the signals were generated by intelligent beings; however nobody in the Cavendish Laboratory at Cambridge University had any other explanation. | The Cavendish group was not able to explain the observations. |
| Hewish and Bell wrote a paper describing the first pulsating source and submitted it to the journal Nature, where it was published on February 1968. | |
| A few months later, after the publication of the findings, Thomas Gold a professor at Cornell University, come out with a good explanation for the pulsed signals. Gold suggested that the radio signals originated from very compact, exceedingly fast-spinning neutron stars. The neutrons stars continuously emit radiation from to poles that usually are not aligned with their rotation axis. When the emitting zones of the neutron stars point toward the Earth, we see the pulse and we do not receive any radio waves until one of the two emitting regions is pointing toward us again. | Gold provided a new **explanation**: neutron stars that were very small, compact stars that spin really fast and emit radio waves in two opposite directions. |
| Neutron stars are the remains of supernovas. Stars like our Sun give off energy because they are formed mainly of hydrogen undergoing nuclear fusion. This process radiates a lot of energy, which is why stars are hot and bright. This radiation also opposes the gravitational attraction of the hydrogen in the star, so prevents the star from collapsing onto itself. | What are neutron stars? How are they generated? |
| During the nuclear fusion process two hydrogen nuclei unite producing one nucleus of helium that is a more massive element and collects together at the core of a star. When it is compressed the helium warms up, and eventually is hot enough to start its own fusion process, producing carbon and oxygen. In heavy stars with masses at least eight times the mass of the Sun, the carbon and oxygen will fuse to produce neon, sodium and magnesium, and later, silicon and sulfur. All of these fusion processes emit energy to keep the star burning. But the silicon and sulfur in the core produce iron when they fuse together. Iron is the most stable form of nuclear matter, and the fusion of iron does not emit energy. In fact, iron requires energy for fusion to take place. The result is that fusion stops at the very centre of the star. | Relation of the **explanation** of neutron stars with other fields of physics. |
| With no radiation from the core, the outer layers of the star begin to collapse in towards the centre, drawn by a gravitational attraction. The iron core is pushed together so tightly that nuclei of iron begin to touch, before emitting an immense shockwave. | |

This shockwave of very high-energy particles spreads outwards through the star and holds enough energy to fuse elements together into isotopes of every imaginable element, including very heavy substances like uranium. The shockwave also spreads inwards through the core with enough energy to convert the protons and electrons of the iron into neutrons. The explosion is so powerful that the supernova will outshine the rest of the galaxy for a month.

After the explosion the neutron core remains, while all the other supernova remnants are carried away by the shockwave. If the original star had a mass of more than 25 times the mass of our Sun then the neutron core will collapse to a black hole. But if the original star was between 8 and 25 times the mass of our Sun, the neutron core would remain as a neutron star, with a mass up to three times the mass of our Sun. Neutron stars have a diameter of around 30 km and are incredibly dense at 1018 $kg/m^3$. A teaspoonful of neutron star material would weigh as much as a mountain.

These neutron stars are spinning incredibly fast. The gigantic stars from which they formed would have had rotational periods similar to that of our Sun, which rotates about once every 27 days. But these stars have now collapsed into an incredibly dense object only 30 kilometers across. When a rotating mass is moved closer to its centre of rotation, the speed of rotation has to speed up to maintain the angular momentum. A star that rotated once a month can end up rotating once per second after its collapse into a neutron star.

The neutron stars have incredibly high magnetic fields, which produce strong radio signals from the star in two opposite directions. As the star rotates these radio signals are swept around the sky in a circle. This was the 'lighthouse' explanation of the pulsars, which Gold had proposed.

Anthony Hewish was awarded the Nobel Prize for Physics in 1974 for the discovery of pulsars, along with Martin Ryle (the head of the Cavendish laboratory) for his work with radio telescopes. Sadly Jocelyn Bell, despite her instrumental role in the discovery of pulsars, did not share the prize.

**Explanation** of the small size and high density of neutron stars.
It is not mentioned how this information was gained but it probably will take a lot of space.

**Explanation** of the high spinning speed of the neutron stars follows Model of conservation of angular momentum **applied.**
**Prediction** (based on conservation of angular momentum)

**Explanation,** without details, of the radio emissions of pulsars, and how we observe the pulses.
Nice **analogy** to a lighthouse, helps to visualize what is happening

Recognition of worth of the work of women has been difficult to attain.