Astronomy 16

"Stellar and Planetary Astronomy"

Spring 2012

Course Description:

This course provides an introduction to the physical principles describing the formation and evolution of stars and their planetary companions. Topics include thermal radiation and stellar spectra; telescopes; energy generation in stars; stellar evolution; orbital dynamics; the Solar system; and exoplanets. This course includes an observational component: students will determine the distance to the Sun, and use the Clay Telescope atop the Science Center to study stellar evolution and detect exoplanets.

Role as a Teaching Fellow:

As in many Harvard classes, much of the interaction with the students outside of lectures was left to the teaching fellows. In my capacity as a T.F., I held weekly problem sessions, taught two laboratories, graded all student work, and was available for additional office hours.

Teaching Evaluation:

At the end of the course, students filled out online evaluations of both the overall course and my teaching. Overall, I received very high scores and favorable comments. I received a slightly lower score for 'Gives useful feedback on assignments,' so I have tried to improve upon this in other teaching endeavors. In the second class I taught at Harvard (Astronomy 17), I gave each student a typed page of comments and suggestions for each lab report turned in over the course of the semester. I also gave students the chance to turn in a draft report before the final deadline to receive feedback and tips for completing the assignment.

Awards:

Received the Harvard University Certificate of Distinction in Teaching

Charbonneau, David

	na	1	2	3	4	5	Tot.	Response Rate	Mean
Evaluate your Instructor overall.		**0**	**0**	**1**	**5**	**28**	**34**	**87.18%**	**4.79**
Gives effective lectures or presentations, if applicable	0	0	0	0	5	30	35	89.74%	**4.86**
Is accessible outside of class (including after class, office hours, e-mail, etc.)	0	0	2	4	15	14	35	89.74%	**4.17**
Generates enthusiasm for the subject matter	0	0	0	1	4	29	34	87.18%	**4.82**
Facilitates discussion and encourages participation	6	0	0	3	9	17	29	74.36%	**4.48**
Gives useful feedback on assignments	24	0	0	1	3	7	11	28.21%	**4.55**
Returns assignments in a timely fashion	24	0	0	0	4	7	11	28.21%	**4.64**

EVALUATION OF TEACHING FELLOWS

MacGregor, Meredith Ann

	na	1	2	3	4	5	Tot.	Response Rate	Mean
Evaluate your Section Leader overall.		**0**	**0**	**0**	**1**	**9**	**10**	**25.64%**	**4.90**
Gives effective lectures or presentations, if applicable	3	0	0	0	1	6	7	17.95%	**4.86**
Facilitates discussion and encourages participation	2	0	0	0	2	6	8	20.51%	**4.75**
Is accessible outside of class (including after class, office hours, e-mail, etc.)	0	0	0	0	0	10	10	25.64%	**5.00**
Generates enthusiasm for the subject matter	0	0	0	0	1	9	10	25.64%	**4.90**
Gives useful feedback on assignments	0	0	0	1	0	9	10	25.64%	**4.80**
Returns assignments in a timely fashion	0	0	0	1	0	9	10	25.64%	**4.80**

QUESTIONS FOR GENERAL EDUCATION

	na	1	2	3	4	5	Tot.	Response Rate	Mean
How much did this Gen Ed course meet at least one of these goals? (1=none; 2=very little; 3=some; 4=quite a bit; 5=a great deal)	6	0	1	6	5	16	28	71.79%	**4.29**

Unless indicated in the question text, the following scale is used for responses: 1=unsatisfactory; 2=fair; 3=good; 4=very good; 5=excellent.

PLEASE COMMENT ON YOUR SECTION LEADER'S TEACHING.

MacGregor, Meredith Ann

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is fantastic. She is easy to talk to and makes even the most complicated subjects easy to understand. She is the best TF I have encountered in any class.

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is amazing! She made me like Physics when I thought I would have nothing more to do with it. Always responsive on emails, always helpful and scheduling meetings with students even during her own finals. Really, I think she might have been one of the best (if not THE BEST) teaching fellow I've had during my career at Harvard!

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith was always always always available to answer my questions over email or meet outside of class. She helped me so much throughout this class. Great teacher and section leader.

Evaluate the course overall.: **4 (very good)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is one of the most responsive and helpful TFs I've ever had. She was always available to help with problem sets and labs whether via email or in person.

HARVARD UNIVERSITY

CERTIFICATE OF DISTINCTION IN TEACHING

Meredith MacGregor

has been recognized for excellence in teaching
during the Spring semester of 2012.

This certificate acknowledges a special contribution to the teaching of undergraduates in Harvard College.

Terry K. Aladjem
Executive Director
Derek Bok Center for Teaching & Learning

Jay M. Harris
Dean of Undergraduate Education

DEREK BOK CENTER FOR TEACHING AND LEARNING

Astronomy 17

"Extragalactic Astronomy and Cosmology"

Fall 2012

Course Description:

This course provides an introduction to the physical principles describing galaxies and the composition and evolution of the Universe. Topics include the interstellar medium; star clusters; the structure and dynamics of the Milky Way; other galaxies; clusters of galaxies; active galaxies and quasars; cosmology; and the early universe. This course includes an observational component: In addition to observing galaxies with the Science Center Clay Telescope, students will use the millimeter-wavelength telescope at the Harvard-Smithsonian Center for Astrophysics to measure the rotation velocity of the Milky Way galaxy and to determine its mass.

Role as a Teaching Fellow:

As in many Harvard classes, much of the interaction with the students outside of lectures was left to the teaching fellows. In my capacity as a T.F., I held weekly problem sessions, taught two laboratories, graded all student work, and was available for additional office hours.

Teaching Evaluation:

At the end of the course, students filled out online evaluations of both the overall course and my teaching. Overall, I received very high scores and favorable comments. I received a slightly lower score for 'Facilitates discussion and encourages participation.' Since I only taught problem sessions and laboratories for this class, I did not have much of an opportunity to lead student discussions. However, I would like to incorporate more of this in future classes I teach. It might be helpful to incorporate some element of discussion and course review in problem sessions. Oftentimes, these sessions simply turn into 'homework help,' but I think that they could have a much richer purpose if structured slightly differently.

Awards:

Received the Harvard University Certificate of Distinction in Teaching

Eisenstein, Daniel James

	na	1	2	3	4	5	Tot.	Response Rate	Mean
Evaluate your Instructor overall.		**0**	**3**	**9**	**13**	**8**	**33**	**97.06%**	**3.79**
Gives effective lectures or presentations, if applicable	0	0	4	6	12	12	34	100.00%	**3.94**
Is accessible outside of class (including after class, office hours, e-mail, etc.)	7	0	3	6	12	5	26	76.47%	**3.73**
Generates enthusiasm for the subject matter	0	0	4	7	12	11	34	100.00%	**3.88**
Facilitates discussion and encourages participation	7	1	1	4	12	7	25	73.53%	**3.92**
Gives useful feedback on assignments	29	0	1	0	1	1	3	8.82%	**3.67**
Returns assignments in a timely fashion	27	0	0	0	2	3	5	14.71%	**4.60**

EVALUATION OF TEACHING FELLOWS

MacGregor, Meredith Ann

	na	1	2	3	4	5	Tot.	Response Rate	Mean
Evaluate your Section Leader overall.		**0**	**0**	**0**	**3**	**14**	**17**	**50.00%**	**4.82**
Gives effective lectures or presentations, if applicable	7	0	0	0	4	6	10	29.41%	**4.60**
Facilitates discussion and encourages participation	5	0	0	0	5	7	12	35.29%	**4.58**
Is accessible outside of class (including after class, office hours, e-mail, etc.)	0	0	0	0	2	15	17	50.00%	**4.88**
Generates enthusiasm for the subject matter	1	0	0	0	2	14	16	47.06%	**4.88**
Gives useful feedback on assignments	3	0	0	0	3	11	14	41.18%	**4.79**
Returns assignments in a timely fashion	3	0	0	0	0	14	14	41.18%	**5.00**

QUESTIONS FOR GENERAL EDUCATION

	na	1	2	3	4	5	Tot.	Response Rate	Mean
How much did this Gen Ed course meet at least one of these goals? (1=none; 2=very little; 3=some; 4=quite a bit; 5=a great deal)	1	2	2	7	9	13	33	97.06%	**3.88**

QUESTIONS PROVIDED BY THE INSTRUCTOR

	na	1	2	3	4	5	Tot.	Response Rate	Mean
The study questions improved my comprehension of the course readings. (1=strongly disagree; 2=disagree; 3=neither agree or disagree; 4=agree; 5=strongly agree)	0	0	2	3	13	16	34	100.00%	**4.26**

PLEASE COMMENT ON YOUR SECTION LEADER'S TEACHING.

MacGregor, Meredith Ann

Evaluate the course overall.: **3 (good)**
Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is a wonderful TF. She makes everything much more accessible and is very approachable.

Evaluate the course overall.: **4 (very good)**
Evaluate your Section Leader overall.: **5 (excellent)**

always there to help!

Evaluate the course overall.: **4 (very good)**
Evaluate your Section Leader overall.: **5 (excellent)**

Meredith wasn't my TF but since she was head TF, I did come into contact with her regarding many things. She was very encouraging and helpful during pset sessions, and many a time saved my life with the reading questionnaires if I had missed them by a little margin of time. :)

Evaluate the course overall.: **4 (very good)**
Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is awesome! She explains things very well and her comments not he homework are detailed and insightful (and often witty). She is also very good at helping prepare for exams, answering emails promptly. I also appreciated how she noticed improvement in coursework and encouraged me! She is also a very fair grader.

Evaluate the course overall.: **5 (excellent)**
Evaluate your Section Leader overall.: **5 (excellent)**

Great at explaining. Always available. Meredith is a stellar teaching fellow.

Evaluate the course overall.: **4 (very good)**
Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is the best TF at Harvard! She can make even the most complicated material accessible, and she's so nice to everybody all the time! It was great to have her as a resource in Astro 17 (she was fantastic in Astro16 too!)

Evaluate the course overall.: **3 (good)**
Evaluate your Section Leader overall.: **4 (very good)**

Meredith was always available to help and was very enthusiastic about the material. She was great!

Evaluate the course overall.: **4 (very good)**
Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is really accessible and is patient in helping you understand a concept

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is a great TF showing a lot of enthusiasm and encouragement for students. The lab sections were really helpful times. She always summarized the crucial concepts for the labs and summarized the major concepts that we learned in class for the midterms. Regarding the problem sets, she is really helpful at simplifying some of the harder concepts involved. The comments on the homework were really insightful and encouraging as well! Overall, Meredith really made the course fun and enjoyable.

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is very careful and clear in her explanations of course material, and very prompt with answering emails.

Evaluate the course overall.: **4 (very good)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith was definitely the best TF I had this semester, I see her as a friend more than a TF now. She helped me so much, always encouraging me. She was always reachable by e-mail and carefully answered all my questions. People like her motivate me to continue studying astrophysics in the future, as I love working in their company. A big thank you for everything, and I really hope we keep in touch.

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Very keen to help!

Evaluate the course overall.: **5 (excellent)**

Evaluate your Section Leader overall.: **5 (excellent)**

Meredith is not actually my section leader, but because she taught me in Astronomy 16 I sometimes went to her when I needed help. Like Ian, Meredith is extremely prompt in replying to emails and has been extremely helpful throughout the semester. Definitely a gem of the Astronomy department.

HARVARD UNIVERSITY

CERTIFICATE OF DISTINCTION IN TEACHING

Meredith MacGregor

has been recognized for excellence in teaching
during the Fall semester of 2012.

This certificate acknowledges a special contribution to the teaching
of undergraduates in Harvard College.

Robert A. Lue
Richard L. Menschel Faculty Director
Derek Bok Center for Teaching & Learning

Jay M. Harris
Dean of Undergraduate Education

DEREK BOK CENTER FOR TEACHING AND LEARNING

Stargazing Through the Centuries: Astronomy in a Historical Context

SPU XX

T/Th 10:30 AM

Location TBA

Harvard University

Summary and Course Objectives

Welcome to Stargazing Through the Centuries! Since the dawn of civilizations, mankind has tried to make sense of the Universe we live in. This course follows how our understanding of space and the Universe has evolved over this extensive history. We will look briefly at ancient views of astronomy and then delve into the invention of the telescope and Galileo's first look at the moons of Jupiter. Then, we will trace the progress of astronomical knowledge through to the modern day and conclude by discussing our first glimpse of planets around stars other than our Sun. Over the course of the semester, we will delve into some of the most significant and astonishing discoveries in astronomy and see what those discoveries can tell us about the world we live in. But, perhaps most importantly, this course is about connections. By following this story from the beginning through to today, we will be able to view the process of science and how discoveries build upon one another. Scientific knowledge does not exist in a stasis, but is instead constantly changing, evolving, and building on itself. How did we develop the understanding of the Universe we have today? What role did technology play in getting us here? And, where might we be going in the coming years and decades? After taking this course, you should be able to answer a few of these important questions for yourself!

Course Details

Course website: https://www.cfa.harvard.edu/~mmacgreg/

Required Readings:

Marc L. Kutner, *Astronomy: A Physical Perspective* (Cambridge University Press 2003), ISBN: 978-0521529273

Marcia Bartusiak, *Archives of the Universe* (Random House 2010), ISBN: 978-0375713682

. . . and, excerpts from various other sources!

Course Goals

This course aims to achieve two purposes: (1) to increase your awareness of the scientific process and its role in our world and (2) to give you academic and professional skills that will benefit you in your ultimate careers. As such, the course goals can be divided along similar lines.

By the end of this course, you will . . .

Professional and Personal Goals:

- Be able to read technical articles efficiently for key concepts
- Have experience working and discussing in a group setting
- Be able to use analytical and mathematical skills to solve problems
- Acquire critical thinking skills by learning to evaluate the evidence behind a scientific theory
- Learn how to formulate, test, and evaluate hypotheses through relevant hands-on experiments

Scientific Goals:

- Learn fundamental concepts in astrophysics that will equip you to better understand new scientific discoveries made in the coming years and decades
- Have an understanding of the roles science and technology play in our everyday lives and culture
- Understand astrophysics as a way to describe our real physical world
- Come to view science as a constantly evolving process instead of a static set of rules and equations
- Be able to synthesize and integrate new information and ideas into their personal scientific framework
- Have an understanding of the techniques and methods used to gain new knowledge in physics and astronomy

Beyond these learning goals, this course aims to develop specific skills in line with the goals of the General Education program for Science of the Physical Universe.

Your Instructor

Meredith MacGregor mmacgreg@cfa.harvard.edu
Office phone: (617) 495-4484
Harvard-Smithsonian Center for Astrophysics
60 Garden St.
A-104

Office Hours: M/W 10-11 AM

I am eager to meet with you outside of class to discuss the course or astronomy in general. If these times don't work for you, please email me to set up an appointment!

Course Requirements and Grading

Problem Sets and Lab Reports (20%)

There will be a total of 7 problem sets and 3 short lab reports assigned over the course of the semester. These will be handed out one week prior to the due date. Labs will be carried out in lieu of section on the relevant weeks. Lab reports are expected to be of comparable length to standard assignments, but will give you an opportunity to see what it is like to do real astronomical research. All assignments will be due at the beginning of lecture and since we will hand out solutions at that time, no late assignments will be accepted. However, we will drop the lowest score from the set of 10 total assignments.

Class and Lab Participation (5%)

I expect that you will attend all lectures and sections. I do understand that sometimes things come up that are beyond your control (illness, etc.). However, please make every effort to attend and engage in the course material.

Reading Assignments (5%)

Readings will be assigned once a week and are your first encounter with the material to be covered in lecture on a given week. A brief online questionnaire on the assigned readings will be due each Monday at midnight. The purpose of this questionnaire is twofold: (1) it allows me to verify that you have completed the readings and (2) it gives me a chance to tailor my lectures for the week to your areas of interest or confusion. These questionnaires will be evaluated on a 2-point scale, where 2 indicates that you have completed the readings, 1 indicates room for improvement, and 0 is incomplete or unsatisfactory.

Timeline of Astronomy (10%)

Over the course of the semester you will be asked to complete a personal 'Timeline of Astronomy' synthesizing the material from lecture into a cohesive format (more instructions to be handed out soon!). Each month, you will turn your 'in progress' timeline into your TF for evaluation. The TF will score you on a 2-point scale and provide feedback on how to improve your timeline. At the end of the semester, you will turn in your completed timeline for a final grade.

Final Project (15%)

The final project of the course allows you to explore a topic discussed in lecture in much greater detail and then to present your results in a creative way. All of your final projects will be incorporated into our class 'Timeline of Astronomy.' More details to follow!

Midterm Exam (15%)

We will hold one midterm exam in class on Thursday, XX/XX/XX. All students are expected to take the exam at this time. If you have a conflict, please let me know immediately. Under exceptional circumstances, we can make alternate arrangements for a make-up, but these accommodations will need to be arranged will in advance.

Final Exam (30%)

The date of the final 3-hour exam will be set by the Office of the Registrar and announced roughly halfway through the semester. Please note that the Administrative Board of Harvard College has sole jurisdiction over granting make-up final exams.

Grading

The course will graded on an absolute scale with the following letter grade assignments:

90-100%	75-89%	60-74%	50-60%	<50%
A, A-	B+, B, B-	C+, C, C-	D	E

Astronomy Laboratories

For three weeks during the semester, laboratories will replace regular section meetings. This is meant to mix up the routine of typical problem sets, by giving you a chance to work with real data and to see what real astronomical research is like. The order of these three labs is as follows:

Week 3: Galileo and Jupiter's Moons

We will recreate Galileo's historical observations, by observing Jupiter's Galilean moons ourselves. To do this, we will use the Clay Telescope on the roof of the Science Center.

Week 6: Spectroscopy

We will learn the basics of spectroscopy. We will begin by looking at the spectra of several common elements and then compare these to the observed spectrum of the Sun.

Week 8: Galaxies Other Than Our Own

We will use data from a millimeter wave telescope located at the CfA to calculate the rotation curve of our own Milky Way galaxy.

On weeks that there are labs, the usual homework assignment will be replaced by a brief lab report. These lab reports will be of a comparable length to a typical homework assignment and will consist of several questions that you should investigate and provide answers to after performing some basic data analysis. They are certainly not meant to be a considerable undertaking and count for the same percentage of the final grade as any other homework assignment.

Policy on Collaboration

We encourage you to collaborate in class, in section, and on the homework assignments. This course is graded on an absolute scale, which is intended in part to eliminate any worries the you might lower your own grade by helping others. Your fellow classmates are a very important resource to help you understand the course material. The best strategy is to attempt all of the problems on the assignment on your own, before consulting others. That way you will benefit the most from your discussions afterwards. If you collaborate on a homework assignment or lab report, you must (1) state the names of the students with whom you collaborated, and (2) submit your own individual, original solutions or write-up, which you write without consulting someone else's solutions. Work that matches closely with that of another student, or for which you do not state the names of your collaborators, is unacceptable.

Week	Lecture	Topics	Readings	Assignments
1	Tues.	**Introduction and Early Astronomy** *What did the ancient Greeks really know about astronomy?*		
	Thurs.	**The New Heliocentric View** *What prompted Copernicus to propose his new theory?*	*Archives of the Universe*, p. 53-68	Pset #1 assigned
2	Tues.	**The Invention of the Telescope** *How did this new instrument change astronomy forever?*	Kutner, Ch. 4, p. 41-52	
	Thurs.	**The Discoveries of Galileo** *How did Galileo's work set the stage for the astronomers that came after him?*	*Starry Messenger* selections *Archives*, p. 76-96	**Pset #1 due** Pset #2 assigned
3	Tues.	**Kepler's Laws of Planetary Motion** *What important predictions did these fundamental laws make?*	NASA's page on Kepler	
	Thurs.	**Newton and Gravitation** *What other course topics have this fundamental theory as their foundation?*	*Archives*, p. 97-106	**Pset #2 due** Lab #1 in section
4	Tues.	**New Solar System Objects** *How did we miss these objects and how did we finally find them?*	*Archives*, p. 107-115, 128-133 ,and p. 149-189	
	Thurs.	**The Beginning of Spectroscopy** *What is a spectrum and why is it a useful tool in astronomy?*	Kutner, Ch. 4, p. 60-62 *Archives*, p. 203-210	**Lab #1 due** Pset #3 assigned Timeline Check #1
5	Tues.	**Measuring Distance in Space** *How do we measure distances in astronomy?*	*Archives*, p. 226-231	
	Thurs.	**The Sun** *What do we know about the closest star to us?*	Kutner, Ch. 6 *Archives*, p. 211-217	**Pset #3 due**
6	Tues.	**Everything Stars!** *What can we learn about other stars and how do we learn it?*	Kutner, Ch. 9	
	Thurs.		*Archives*, p. 233-249	In class midterm Lab #2 in section
7	Tues.	**Star Formation and Stellar Evolution** *How do stars form and evolve?*	Kutner, Ch. 15	
	Thurs.		Kutner, Ch. 10 *Archives*, p. 377-397	**Lab #2 due** Pset #4 assigned

Week	Lecture	Topics	Readings	Assignments
8	Tues.	**The Cosmic Distance Ladder** *How do we determine distances when are usual methods fail?*	Kutner, Ch. 10, p. 179-183	
	Thurs.	**Hubble and Galaxies** *How did we come to realize that there are galaxies other than our own?*	Kutner, Ch. 18, p. 339-345 *Archives*, p. 413-414	**Pset #4 due** Lab #3 in section Timeline Check #2
9	Tues.	**New Wavelengths of Observation** *What can we learn about the Universe using other wavelengths of light?*	Kutner, Ch. 4, p. 62-77 *Archives*, p. 449-464, p. 495-502, and 522-528	
	Thurs.	**The Discovery of the CMB** *How did this discovery change our notion of the formation of the Universe?*	*Archives*, p. 363-376	**Lab #3 due** Pset #5 assigned
10	Tues.	**Mapping the Universe** *How did we start to map and unravel the structure of the Universe?*	Kutner, Ch. 18, p. 345-351 *Archives*, p. 583-590	Start thinking about the topic for your final project
	Thurs.	**The Space Age** *How did the invention of rockets and the space program impact astronomy?*	Kerbal Space Program resources	**Pset #5 due** Pset #6 assigned
11	Tues.	**New Telescopes, New Discoveries** *How did sending telescopes into space expand our astronomical horizons?*	*Archives*, p. 591-599	
	Thurs.	**Introduction to Modern Observations and Cosmology** *What are our modern views?*	Kutner, Ch. 20-21 selections	**Pset #6 due** Pset #7 assigned **Project topic due**
12	Tues.	**Modern Cosmology** *How do we think the Universe formed and how do we know that?*	Kirshner, *Extravagant Universe* selections *Archives*, p. 415-424	
	Thurs.		*Archives*, p. 576-582	**Pset #7 due** Timeline Check #3
13	Tues.	**Worlds Other Than Our Own** *How do we learn about planets around other stars?*	*Archives*, p 600-623	
	Thurs.		Seager, "Introduction to Exoplanets"	**Final project due** Final timeline due

Astronomical Timelines

Science is all about connections, both historical and physical. Each new discovery builds off of previous knowledge and provides a stepping-stone for future science. In astronomy, this is particularly true. Since the invention of the telescope we have continually been improving our technology and, as a result, exploring further and further into the depths of our Universe. For Galileo, it was heresy to suggest that the Earth was not the center of the Universe. Today, we are learning about planets around other stars and even about the initial formation of our Universe (you'll learn more about the recent BICEP-2 discovery in a future assignment!). We have certainly come a long way in our understanding of astronomy. But, to better appreciate that, we have to keep in mind how we got to where we are today and where we might be going in the years after you leave Harvard.

This assignment serves two purposes. The first is to give you a better understanding of connections in astronomy. By creating a 'Timeline of Astronomy,' you will begin to see the process of scientific discovery and the 'baton pass' from student to teacher that pushes science forward. The second part of the assignment allows you to take your new understanding of how astronomical discoveries fit together and turn it into something creative that synthesizes the information in a way accessible to the general public.

Assignment Overview:

This assignment has two parts:

1. Develop a 'Timeline of Astronomy' over the course of the semester
2. Pick one of the significant astronomical discoveries we discussed in the course, do additional research to understand it more deeply, and then develop a creative project that presents your new knowledge to the rest of the class

Don't worry if this seems overwhelming! This assignment is intended to stretch over the whole semester, with several smaller due dates along the way to help keep you on track.

Part 1: Individual Timeline

The purpose of this assignment is to synthesize the material from lecture into a 'Timeline of Astronomy.' Let's be a bit more specific. Your timeline might start with the following entry:

> **1543-** Nicolaus Copernicus' renowned book discussing a heliocentric worldview, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), is first published.

You should then link that entry to subsequent important events or discoveries in astronomy. For example, your timeline might continue as follows:

→ **1543-** Dutch eyeglass maker Hans Lippershey first develops a magnification device that became known as the 'telescope.' → **1610-** Galileo first sees the moons of Jupiter through a telescope and publishes his discovery in *Sidereus Nuncius (Starry Messenger)* leading to his affirmation of the Copernican heliocentric model of the Solar System. →

Over the course of the semester, you will build up a complete trajectory of scientific discovery. Here are a few things to keep in mind:

1. Your timeline entries should include enough information that another reader of your timeline would clearly understand the importance of each event. For example, instead of writing "Galileo discovers the moons of Jupiter," you might instead write "Galileo discovers the moons of Jupiter, which led to his affirmation of the Copernican heliocentric model of the Solar System." The second sentence conveys both the discovery *and* the ultimate significance of it.
2. Try to emphasize connections! If Galileo was only able to see the moons of Jupiter because of the invention of the telescope, make sure that is clear in your timeline.

We have obtained a course account for the online interactive timeline tool Tiki-Toki (*http://www.tiki-toki.com*). Instructions for setting up your own Tiki-Toki account will follow in a subsequent document. This website provides you with a simple tool to create your timeline for this course. Then, each month, you will simply provide a link to your online timeline to your TF for checking and grading purposes.

Our 'official' course timeline . . .

At the end of each month, the TFs will be posting the 'official course timeline' to the website using the same interactive timeline tool, Tiki-Toki. You can use this 'official' timeline to compare your own work to what your TFs think is most important to keep in mind. Combining this with the comments you receive on your own timeline each month should help you develop your understanding of the course material further. And, of course, you can check what important discoveries and connections you might be missing, so that you can make your final graded product that much better!

Important due dates:

- Last section of each month: Turn in your timeline as it stands to your TF. Timelines will be returned the following week with comments. This will help keep you up to date with the course material, so you don't have to rush to finish at the end of the semester.
- Final class: Turn in your finalized timeline to your TF to be included in your final grade for the course.

Over the course of the semester, your TFs and myself will be available during office hours to discuss the timeline and any questions you might have.

Part 2: Creative Further Exploration

This second assignment is designed as an add-on to the first timeline assignment. It will give you a chance to explore a significant astronomical discovery, the events leading up to it, and its impact on future science. And, it will let you consider all of this *creatively*! Each person in the course will select a significant milestone in the history of astronomy, say, Galileo's discovery of the moons of Jupiter. Next, you will do additional research to learn more about the science of that discovery and its historical context. Finally, you will condense this research into a final project that presents your new understanding in a fun and creative way at a level that is accessible to the general public. We are leaving it up to you what kind of format your final project will take. Let's consider our example topic further. If you chose to do Galileo and Jupiter's moons, your final project might discuss Copernicus and the heliocentric model of the Solar System, the invention of the telescope, Galileo's actual observations, our current understanding of the structure of the Solar System, . . . The list can go on and on! For obvious reasons, we don't expect your video to discuss *every* possible connection and nuance of this discovery. The trick will be distilling all of this information down to what best represents the science and the connections you want to emphasize.

A few critical details . . .

We are leaving it up to each of you to decide what form your final project will take. You can choose to do a video, podcast, website, blog post, etc. The majority of your final grade will be based on the content of your project. However, we encourage you to be as creative as you want! The goal of the project is to deepen your understanding of a significant astronomical discovery, while also emphasizing that science can be learned and presented in ways that are more creative than the typical research paper. If you need some inspiration to get started, check out this wonderful YouTube video created for the 400th anniversary of Galileo's discoveries:

https://www.youtube.com/watch?v=l8WBMlmWJLo

This should give you a good idea of how your project might demonstrate the connections and process of scientific discovery. Keep in mind you should include a bit more content than this example. And, of course, we don't expect a polished music video or original composition. A simple and clear presentation is perfectly adequate. But, don't hesitate to be as creative as you want to be!

On a final note, we will be incorporating all of your final projects into our completed 'official course timeline.' When you turn in your project, we will add it as an insert to the online interactive timeline (we will demonstrate how this will work in class). After everyone has completed their project, you will be able to click on each event in the timeline and see the work your classmates have done over the semester. In the end, this comprehensive timeline should prove to be an excellent study tool for the final exam!

Important due dates:

Week 10: Select a topic

Week 11: Meet with your TF to discuss your plans for the final project
* Turn in a two-page description of topic and connections you might focus on. Make sure to include 3-5 sources you plan on using.

Week 12: Continue working on your project

Week 13: Finalize your project
*Turn in the finalized project on the last day of class!

Motivation for this assignment:

This course emphasizes connections, both historical and physical, within astronomy. Sometimes it is easier to see those connections when they are presented visually. The first part of this assignment aims to solidify those connections for the students by asking them to create a 'Timeline of Astronomy' over the course of the semester, which they will eventually be able to use on the final exam. The second part of this assignment aims to show students that science can be creative, not simply memorizing facts and equations out of a textbook. Students will use their imagination and creativity to turn a piece of their timeline into a creative project that not only explains the relevant connections at a deeper level, but also presents the material at a level appropriate for the general public.

**This will not be shared with the students, but provides a bit more context as to how this assignment was created and formatted.*

Name: ________________________________

Feedback on Timeline Check #__________

0	1	2
Timeline is incomplete or not turned in at all. No connections between discoveries are evident.	Timeline is missing some significant pieces from lecture, but is mostly complete and connections between events are clear.	Timeline includes all significant pieces from lecture. Connections between entries are clear.

Score: __________

Comments and Suggestions:

Stargazing Through the Centuries: Astronomy in a Historical Context

Course Rationale

Course Description

Since the dawn of civilizations, mankind has tried to make sense of the Universe we live in. This course follows how our understanding of space and the Universe has evolved over this extensive history. We will look briefly at ancient views of astronomy and then delve into the invention of the telescope and Galileo's first look at the moons of Jupiter. Then, we will trace the progress of astronomical knowledge through to the modern day and conclude by discussing our first glimpse of planets around stars other than our Sun. Over the course of the semester, we will delve into some of the most significant and astonishing discoveries in astronomy and see what those discoveries can tell us about the world we live in. But, perhaps most importantly, this course is about connections. By following this story from the beginning through to today, we will be able to view the process of science and how discoveries build upon one another. Scientific knowledge does not exist in a stasis, but is instead constantly changing, evolving, and building on itself. How did we develop the understanding of the Universe we have today? What role did technology play in getting us here? And, where might we be going in the coming years and decades? After taking this course, students should be able to answer a few of these important questions for themselves!

Target Audience

This course is designed as a general education level course in astronomy that aims to introduce students to our current understanding of the field as well as to the process of science and its role in our world. Thus, the course will be open to all students who have an interest in learning more about the field of astronomy and our Universe. No prior background in physical sciences will be required.

Why this course?

Most introductory astronomy courses are taught straight from a textbook. A set number of 'crucial' concepts are presented in a fairly arbitrary order without any attempt to build connections between concepts. This method of teaching gives students the false perspective that science consists simply of a collection of known theorems that describe unconnected phenomena. Students in such courses get no perspective on how science is actually undertaken and how it describes a real physical world where each part is intimately connected to every other part. This course was designed to change this view. Over the course of the semester, students will not only learn the fundamental concepts of modern astronomy and astrophysics, but will also be asked to explore how scientific discoveries build off of each other. In addition, students will be exposed to how topics discussed in lecture apply to real world scenarios and applications. By structuring the course in this way, the hope is that the students will come away with a new understanding of science as a process that is continuously evolving over time and that makes predictions about our real physical world.

Course Goals

This course aims to achieve two purposes: (1) to increase students' awareness of the scientific process and its role in our world and (2) to give students academic and professional skills that will benefit them in their ultimate careers. As such, the course goals can be divided along similar lines.

By the end of this course, students will . . .

Professional and Personal Goals:

- Be able to read technical articles efficiently for key concepts
- Have experience working and discussing in a group setting
- Be able to use analytical and mathematical skills to solve problems
- Acquire critical thinking skills by learning to evaluate the evidence behind a scientific theory
- Learn how to formulate, test, and evaluate hypotheses through relevant hands-on experiments

Scientific Goals:

- Learn fundamental concepts in astrophysics that will equip them to better understand new scientific discoveries made in the coming years and decades
- Have an understanding of the roles science and technology play in our everyday lives and culture
- Understand astronomy as a way to describe our real physical world
- Come to view science as a constantly evolving process instead of a static set of rules and equations
- Be able to synthesize and integrate new information and ideas into their personal scientific framework
- Have an understanding of the techniques and methods used to gain new knowledge in physics and astronomy

Beyond these learning goals, this course aims to develop specific skills in line with the goals of the General Education program for Science of the Physical Universe.

Course Format

This course is designed to have biweekly lectures (tentatively, Tuesday and Thursday mornings). In addition to these lectures, weekly sections will be essential. Students will be assigned to sections after enrolling in the course. Starting the second week of classes, sections will meet regularly each week for the remainder of the semester. These sections will serve several purposes, including:

1. An opportunity for teaching fellows (TFs) to clarify and review concepts discussed in lecture that remain unclear to the students

2. A chance for the students to ask questions concerning course assignments
3. Provide hands-on learning experiences through laboratories for students to interact with the real process of doing science

There will be three laboratories over the course of the semester. Each laboratory will be carried out within section and the write-up following will replace the problem set for that particularly week. Currently, laboratories are scheduled to take place in section during weeks 3, 6, and 8 with reports due during weeks 4, 7, and 9. During the other weeks of the semester, section will be reserved for review, questions, discussions, and time to work on assignments.

Relevant Pedagogy

The main pedagogical principle used in designing this course is 'backward design,' meaning that the entire course is structured around a few critical learning goals. Once these learning goals are chosen, the lectures, course calendar, and assignments are all designed to emphasize these goals and to evaluate that they are being met. The first learning goal for this course is that students should leave at the end of the semester with an understanding of science as a process, not simply as a static set of theorems. In order to achieve this goal, the course calendar was designed to emphasize the evolution of astronomy throughout history. The first lectures discuss the invention of the telescope and the first discoveries that depended on this new instrument. Then, the lectures move forward through time, farther out in the Universe, and onwards to better and better technology. In order to assess this goal, students will complete a two-part 'Timeline of Astronomy' project over the course of the semester that will provide a visual tool to illustrate connections between scientific discoveries. The second learning goal for the course is that students will become aware of how concepts discussed in class are relevant to the real world and modern events. To this end, each lecture will end with an introduction to a current topic, event, or discovery that relates to the subject discussed in that lecture. This routine will give students a chance to begin thinking about how the equations and concepts covered in class can be applied in the real physical world. The course problem sets will follow-up on the lectures and assess whether or not students have actually learned how to apply concepts from lecture to real problems. Instead of using 'canned' book problems, the homework assignments for each week will include problems that expand on the applications discussed in class. This format will hopefully give students an opportunity to explore these applied scenarios more fully and begin to see how astronomy really does describe a physical world. The use of 'backward design' in this course means that each week of lectures and assignments connects back to the overarching learning goals. This practice should ensure that these goals are not forgotten over the course of the semester and that the students in the course achieve these goals by the end of the semester.

Astronomy 16
Homework #4 Solutions

Spring 2012

Due: March 2, 2012

Problem 1

We want to make an estimate of how frequently transits of Venus occur. This problem asks us to make this estimate in two ways. First, let's consider the case where the orbits of Earth and Venus are coplanar. We can start by calculating the angular velocity of Venus in Earth's reference frame.

$$\omega_V' = \omega_V - \omega_\oplus = \frac{2\pi}{P_V} - \frac{2\pi}{P_\oplus} \tag{1}$$

Here, P_V is the sidereal period of Venus and $P_\oplus$ is the sidereal period of Earth.

$$\omega_V' = \frac{2\pi}{5387 \text{ hours}} - \frac{2\pi}{8760 \text{ hours}} = 4.49 \times 10^{-4} \text{ rad/hour} \tag{2}$$

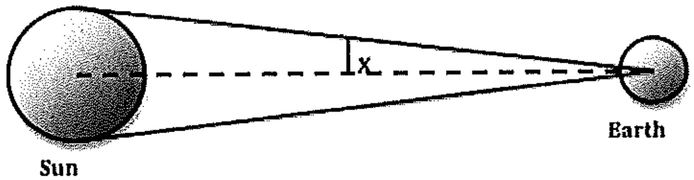
If we start with Earth and the Venus aligned in a transit orientation, we then want to calculatehow long it will take for Venus to make an entire orbit around the Sun and catch back up with the Earth. This is also called the 'synodic' period of Venus.

$$P_{syn} = \frac{2\pi \text{ rad}}{4.49 \times 10^{-4} \text{ rad/hour}} = 13993.7 \text{ hours} \approx \mathbf{1.6 \quad years} \tag{3}$$

We know that this is clearly an underestimate. This is because we made a huge simplification by assuming that the orbits of Earth and Venus are coplanar. In fact, these orbits are misaligned by 3°23'.

Well, for the second part of this problem, we are asked to now take this misalignment into account. A good first step is to calculate the maximum distance above (or below) the ecliptic that Venus can be and still produce a transit. We know that the angular diameter of the Sun is 32 arcminutes (you'll solve for this explicitly in Problem #2). This means that the angular radius of the Sun is about 16 arcminutes or 0.267°. Venus has an orbital radius of 0.72 AU, so it is 0.28 AU or 4.2×10^7 km away from Earth when it could be transiting. If we define a triangle with a hypotenuse from the limb of the Sun to Earth, we can solve for the physical distance that lies above the ecliptic but within the angular diameter of the Sun at Venus' orbital radius:

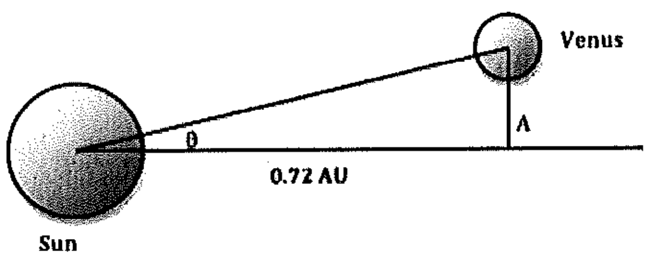
$$\tan\theta = \frac{x}{4.2 \times 10^7 \text{ km}} \rightarrow x = (4.2 \times 10^7 \text{ km})\tan(0.267°) = 1.9 \times 10^5 \text{ km} \tag{4}$$



Furthermore, we know that the height of Venus above the ecliptic as a function of time is a sinusoid, if we assume that Venus has a circular orbit. Thus, we can define a function y that describes Venus' height above the ecliptic:

$$y = A\sin(Bx) \tag{5}$$

Here, x is the number of days and $B = \frac{2\pi}{224.7 \text{ days}}$. A is simply the amplitude of the function. Since we are given that the inclination of Venus' orbit is 3.39°, we can solve for A using trigonometry. We can define a triangle with its base along the ecliptic as is seen below:



The angle θ is just the inclination of Venus' orbit or 3.39°

$$A = (0.72 \text{ AU})\sin(3.39°) = 6.39 \times 10^6 \text{ km} \tag{6}$$

From above, we know that transits can only occur if Venus is 1.9×10^5 km or less above the ecliptic plane. Thus, in order to find the frequency of transits, all we need to do is solve for the fraction of time that the absolute value of our sinusoid function is less than 1.9×10^5 km.

$$1.9 \times 10^5 \text{ km} = (6.39 \times 10^6 \text{ km})\sin\left(\frac{2\pi x}{224.7 \text{ days}}\right) \rightarrow x = 1.06 \text{ days} \tag{7}$$

This solution is only for one quarter of Venus' orbit, so we must multiply this by 4. Then, we can calculate what percent of the time Venus spends sufficiently close to the ecliptic for transits.

$$\left(\frac{4 \times 1.06}{224.7}\right) \times 100 = 1.92\% \tag{8}$$

We can now combine this with our coplanar solution to predict how frequently we expect transits to occur.

$$\text{time between transits} = \frac{1.6 \text{ years}}{0.0192} = \mathbf{83.3 \text{ years}} \tag{9}$$

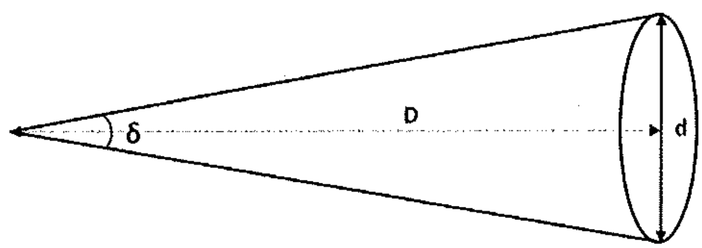
In other words, there is an inferior conjunction of Venus every 1.6 years, but only 1.92% of these conjunctions actually result in a transit.

This is close to the true frequency of transits, but still an underestimation. Why? In reality, the transits of Venus are not evenly spaced. The orbits of Venus and Earth are in an 8 year resonance with each other. So, after about 8 years, Venus and Earth line up in their orbits again. However, this resonance is not quite perfect and after two orbital alignments, Venus reaches the alignment point early and there is not another transit for a long period of time. A great discussion of the timing of transits can be found here:

http://eclipse.gsfc.nasa.gov/transit/catalog/VenusCatalog.html

Problem 2

For this problem, we want to calculate the angular diameter of both Venus and the Sun as viewed from the Earth. The best place to start is to draw a diagram of the geometry we are dealing with.



In this diagram, the Earth is located at the point of the triangle. The actual diameter of the object we want to know the angular diameter of is indicated by d and the distance from Earth to that object is indicated by D. We can then easily define an equation to solve for the angular diameter, δ, using trigonometry:

$$\tan\left(\frac{\delta}{2}\right) = \frac{d/2}{D} \tag{10}$$

Solving this for δ gives,

$$\delta = 2\left(\arctan\left(\frac{d/2}{D}\right)\right) \tag{11}$$

For Venus, $d = 1.204 \times 10^7$m and $D = 4.139 \times 10^{10}$m. Plugging in these numbers we get a value for δ of

$$\delta = 2.909 \times 10^{-4} \text{ radians} = \mathbf{60.0 \quad arcseconds} \tag{12}$$

In order to do this conversion we used the fact that 1 radian = 206265 arcseconds. For the Sun $d = 1.391 \times 10^9$m and $D = 1.496 \times 10^{11}$. So,

$$\delta = 9.298 \times 10^{-3} \text{ radians} = 1.918 \times 10^{3} \text{ arcseconds} = \mathbf{31.9 \quad arcminutes} \tag{13}$$

Thus, the angular diameter of the Sun is $\sim 32\times$ bigger than the angular diameter of Venus. No wonder observers were so surprised by how small the planets appeared compared to the Sun!

In order to compute the fraction of the Sun's light that Venus will block during a transit, we need to compare the solid angles subtended by both objects. The solid angle is defined as:

$$d\Omega = \frac{\pi\delta^2}{4} \tag{14}$$

So, the fraction of light blocked is just the following ratio:

$$f = \frac{\delta^2_{Venus}}{\delta^2_{Sun}} = \frac{(2.909 \times 10^{-4} \text{ radians})^2}{(9.298 \times 10^{-3} \text{ radians})^2} = \mathbf{9.593{\times}10^{-4}} \tag{15}$$

That's a pretty small fraction!

Problem 3

We have two observers on opposite sides of the Earth (North and South Poles). Let's start by considering what the observer at the North Pole observes. We can assume that this observer sees Venus transit at about 42° solar latitude (a typical location for a transit). How long will the transit last? A good place to start is to calculate the angular velocity of Venus in Earth's reference frame. From Problem #1, we have figured out the relative angular velocity of Venus around the Sun:

$$\omega_V^{'} = \omega_V - \omega_\oplus = \frac{2\pi}{P_V} - \frac{2\pi}{P_\oplus} \tag{16}$$

Here, P_V is the sidereal period of Venus and $P_\oplus$ is the sidereal period of Earth.

$$\omega_V^{'} = \frac{2\pi}{5387 \text{ hours}} - \frac{2\pi}{8760 \text{ hours}} = 4.49 \times 10^{-4} \text{ rad/hour} \tag{17}$$

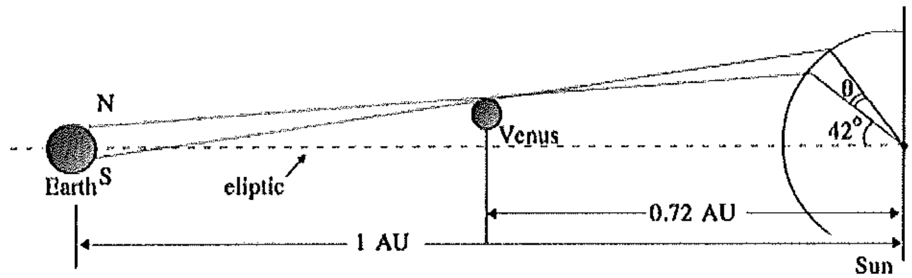
Now, we can calculate the angular distance Venus has to travel to cross the Sun's diameter at a latitude of 42°.

$$x = D_\odot \cos 42° \left(\frac{0.28 \text{ AU}}{0.72 \text{ AU}}\right) = 32' \cos 42° \left(\frac{0.28 \text{ AU}}{0.72 \text{ AU}}\right) = 9.25' = 2.69 \times 10^{-3} \text{ rad} \tag{18}$$

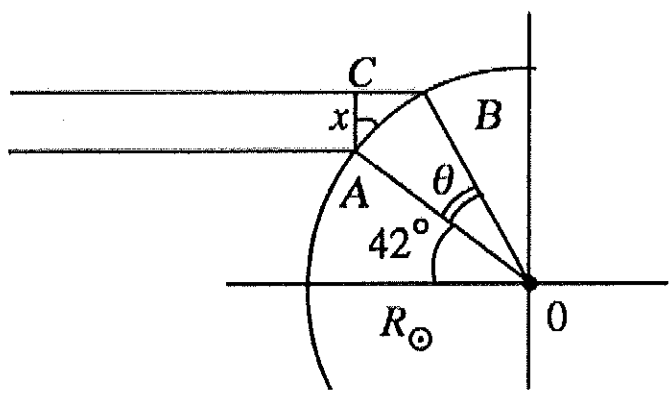
At this point, we need to make an important realization. Our $\omega_V^{'}$ is the relative velocity of Venus to the Earth about the Sun. But, that is not the same as the relative velocity that an observer on Earth would see. To find the appropriate transit time, we need to correct for the angular distance that Venus travels from our perspective on Earth. You can calculate this out by considering the different angles in the problem, but the result is an extra factor of $\frac{0.28 \text{ AU}}{0.72 \text{ AU}}$. Now, the crossing time of Venus is straightforward to calculate.

$$\Delta t = \frac{x}{\omega_V^{'}} = \frac{2.69 \times 10^{-3} \text{ rad}}{4.49 \times 10^{-4} \text{ rad/hour}} = \mathbf{5.99 \text{ hours}} \tag{19}$$

But, what does the observer at the South Pole see? First, we need to figure out what solar latitude the observer at the Sole Pole sees the transit occur at. Maybe a picture will help us understand this problem better.



From this picture we can see that the southern observer sees Venus transit the Sun at a latitude of $42° + \theta$. In order to simplify the calculation, we can assume that the line from Earth to Venus to the Sun is parallel to the ecliptic (not entirely true in reality...). Then we just have to consider the following set-up to solve for θ.



The best place to start is to calculate x. If we assume that the diameter of the Earth and thus the separation between our two observers is about 12,756 km, we can solve for x using similar triangles.

$$\frac{12,756 \text{ km}}{(1-0.72) \text{ AU}} = \frac{x}{0.72 \text{ AU}} \rightarrow x = 32,801 \text{ km} \tag{20}$$

To solve for θ, we need to make a few more assumptions. First, we can assume that θ is very small, so that the segment AB is approximately perpendicular to AO. Also, we know that angle BAC is 42° from the first part of this problem. This gives

$$AB = \frac{x}{\cos 42°} = 44,138 \text{ km} \tag{21}$$

Since θ is small, we can say that the arc length between A and B is about equal to AB. And, we can finally solve for θ!

$$\theta = \frac{AB}{R_\odot} = \frac{44,138 \text{ km}}{6.96 \times 10^5 \text{ km}} = 0.0634° = 3°.63 \tag{22}$$

Thus, we know that the observer at the South Pole sees Venus transit at a latitude of 45°.64.

Finally, we can calculate the difference in observed transit time for the two observers.

$$\Delta t = \frac{x_N - x_S}{\omega'_V} = \frac{D_\odot \cos 42° - D_\odot \cos 45°.63}{1.54'/\text{hour}} \left(\frac{0.28 \text{ AU}}{0.72 \text{ AU}}\right) \tag{23}$$

Here, $D_\odot$ is the angular radius of the Sun or 32'. This gives us a final result of

$$\Delta t = 0.35 \text{ hours} \approx \mathbf{21\ min} \tag{24}$$

The question also asks us to estimate how precisely you need to measure the timing of the transit of Venus in order to determine the AU to a precision of 1%. From above, we have an equation for the time it takes Venus to cross the Sun:

$$\Delta t = \frac{x}{\omega'_V} = \frac{D_\odot(\cos 42° - \cos 45°.64)}{4.49 \times 10^{-4} \text{ rad/hour}} \left(\frac{0.28 \text{ AU}}{0.72 \text{ AU}}\right) \tag{25}$$

We can rewrite this expression to explicitly include the Astronomical Unit:

$$\Delta t = \frac{x}{\omega'_V} = \frac{2\arctan((d/2)/D)(\cos 42° - \cos 45°.64)}{4.49 \times 10^{-4} \text{ rad/hour}} \left(\frac{0.28 \text{ AU}}{0.72 \text{ AU}}\right) \tag{26}$$

This just incorporates the definition of angular diameter into the equation. Now, D is the Astronomical Unit. The official value of the Astronomical Unit from WolframAlpha is $1.495978707 \times 10^{11}$ m. Using this value, we find a time of 0.354191 hours. Increasing the Astronomical Unit by 1% gives us 1.5109385×10^{11} m. Solving the same equation for Δt then yields a result of 0.350684 hours. The difference between these two times is about 0.21 minutes or about 12 seconds. Our equation relating time and the AU is linear, so a 1% change in the AU should correspond to a 1% change in the time. Thus, our answer makes sense. It is actually not that difficult to measure times to an accuracy of a few seconds (we did it in lab), so we can reasonably measure an Astronomical Unit to a precision of 1%. That's a pretty important realization.

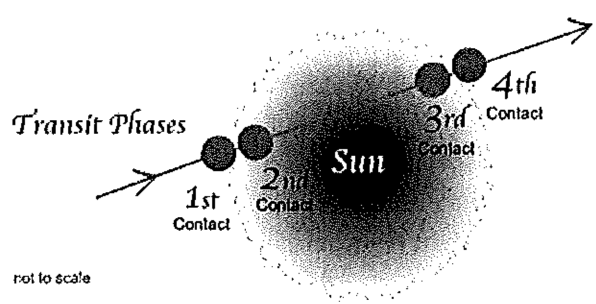
The Dreaded Black Drop Effect is observable when the edge of Venus is just about to reach the edge of the Sun. At this moment, a grayish zone or diffuse shading forms between the outer edge of Venus and the dark sky outside of the solar disk. It is essentially a smearing of the edge of Venus' disk. This effect provides quite a problem for astronomers trying to use Halley's transit timing technique (described below). One explanation of this effect is limb darkening of the Sun. When we look at the edge of the Sun we reach a high opacity at a higher, cooler level in the Sun's atmosphere. Thus, the edge of the Sun appears darker. When we combine this darkening with the inherent blurring of an image through a telescope, the Black Drop Effect is produced. The darkness of the Sun's edge merges with Venus' dark silhouette.

Problem 4

Jeremiah Horrocks: On November 24, 1639, Jeremiah Horrocks made the first observations of the transit of Venus from a small village in Lancashire. Kepler predicted a transit of Venus in 1631. However, the transit occurred at dawn in Europe and was not seen. Then, in 1638, Horrocks calculated that the transits of Venus actually occur in pairs separated by 8 years. This meant that there would be another transit of Venus in 1639. For his observations, Horrocks projected an image of the Sun onto a piece of paper (like we did in lab!). Using his three careful measurements from the transit, Horrocks was able to calculate the transit path, angular size, and orbital velocity of Venus.

William Crabtree: Although Jeremiah Horrocks is often referred to as the "grandfather of British astronomy," William Crabtree's contribution to Horrocks' observations of the transit of Venus was crucial. In about 1638, Crabtree and Horrocks corresponded frequently and concluded from careful telescope observations that the transits of Venus occur in pairs separated by 8 years followed by a longer gap of 122 years. Thus, these two astronomers predicted that there would be a second transit of Venus in 1639. Crabtree made a single observation of this transit, which actually provided a more accurate size determination for Venus than Horrocks' observations of the same transit.

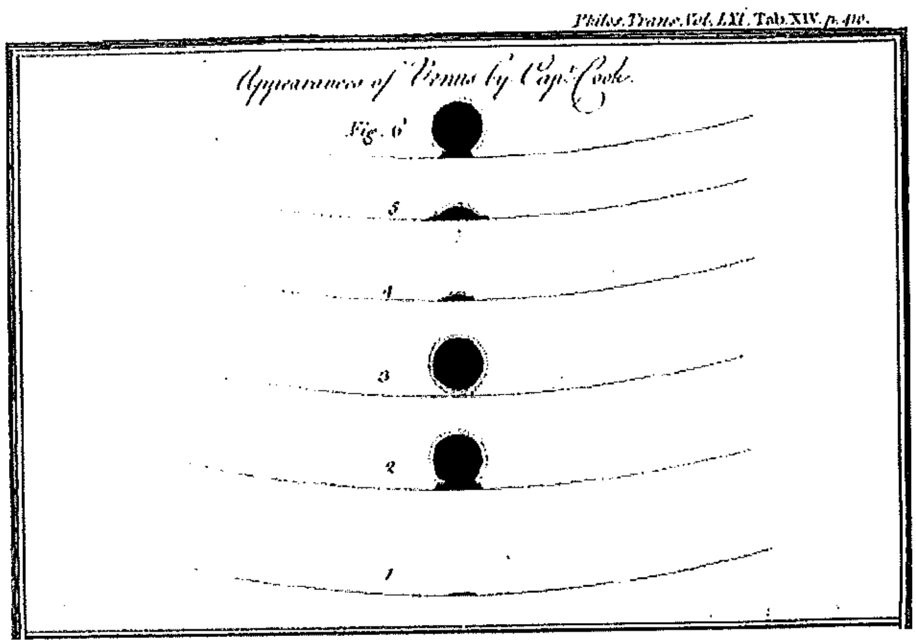
Edmond Halley: In 1716, Edmond Halley first proposed a method of using the transit of Venus to determine the distance between the Earth and the Sun (the astronomical unit). Halley's method was based on the idea of parallax. Two observers at different points on the surface of the Earth would view the transit of Venus at slightly different places on the surface of the Sun. By measuring the difference between these two path lengths, the observers would be able to use trigonometry to calculate the distance from the Earth to the Sun. Halley also proposed that the easiest way to measure the difference in these paths lengths was to accurately measure the time of each transit using defined transit timing phases.



Mikhail Lomonosov: Russian astronomer Mikhail Lomonosov was the first to observe the atmosphere of Venus during its 1761 transit form the Petersburg Observatory. Lomonsov noticed a light 'fire' ring around the planet during the first phase of the transit. This ring was visible on the side of the planet opposite from its direction of motion that had yet to cross in front of the solar disk. Lomonosov correctly concluded that only refraction through a sufficiently thick atmosphere could produce this effect.

Guillaume le Gentil: This is by far the most epic story of an attempt to observe the transit of Venus. The French Academy of Sciences sent Guillaume le Gentil on a voyage in May 1760 to observe the 1761 transit from the French colony of Pondicherry, India. However, when le Gentil finally reached Pondicherry, he found that the colony had been taken over by the British and he was forced to sail to Mauritius. The 1761 event occurred while le Gentil was enroute to Mauritius. Although he did observe the transit, none of his observations proved useful since they were taken from a moving ship. Since there was another transit predicted in 1769, le Gentil chose to stay in Mauritius and then observe the next transit from Manila. Le Gentil arrive in Manila in May 1766, but was not welcomed by the Spanish governor of the colony. So, he went back to Pondicherry (again under French control). However, on the morning of the transit in 1769, the sky clouded over and le Gentil missed the entire event. Le Gentil did not return to France until October 8, 1771 due to a bout of dyssentary, a total of 11 years, 6 months, and 13 days after he had initially set out. Upon his return he discovered that his wife had remarried, his relatives had declared him dead, and he no longer had a position in the French Royal Academy. However, things were eventually sorted out and le Gentil remarried. Yikes!

Captain James Cook: On August 12, 1768, Captain James Cook set out on *HMB Endeavour* to reach the island of Tahiti. England's Royal Academy sponsored the voyage so that Cook could observe the transit of Venus predicted to occur in June of 1769. On June 3, 1769, Cook did in fact observe the transit of Venus. However, his observations were foiled by the Black Drop Effect (the horror!) and did not prove precise enough to determine the astronomical unit to any accuracy. In fact, the transit of Venus was observed at 76 places on the Earth in 1769, but none of the observations were precise enough to set the scale of the astronomical unit. This voyage was a success for many other reasons, though. Cook's crew documented thousands of new species of plants, animals, and insects. Furthermore, the voyage of the *Endeavour* was one of the first times that the British Navy attempted to combat the effects of scurvy.



David Rittenhouse: David Rittenhouse observed the transit of Venus on June 3, 1769 from his farm in Norriton near Philadelphia, Pennsylvania. Rittenhouse was a renowned constructor of clocks, mathematical instruments, and mechanical models of the Solar System. During his observations, Rittenhouse noticed a faint halo around Venus during ingress (start of the transit) and concluded that the planet must have an atmosphere (just like Lomonosov in 1761). Thomas Jefferson wrote about Rittenhouse in his *Notes on Virgina* in 1784: "We have supposed Mr. Rittenhouse second to no astronomer living: that in genius he must be the first, because he is self-taught. As an artist he has exhibited as great a proof of mechanical genius as the world has ever produced. He has not indeed made a world; but he has by imitation approached nearer its Maker than any man who has lived from the creation to this day."

Problem 5

Here in Cambridge. If any of you are still in town, there will be a viewing party from the roof of the Center for Astrophysics :)

2012 Transit of Venus

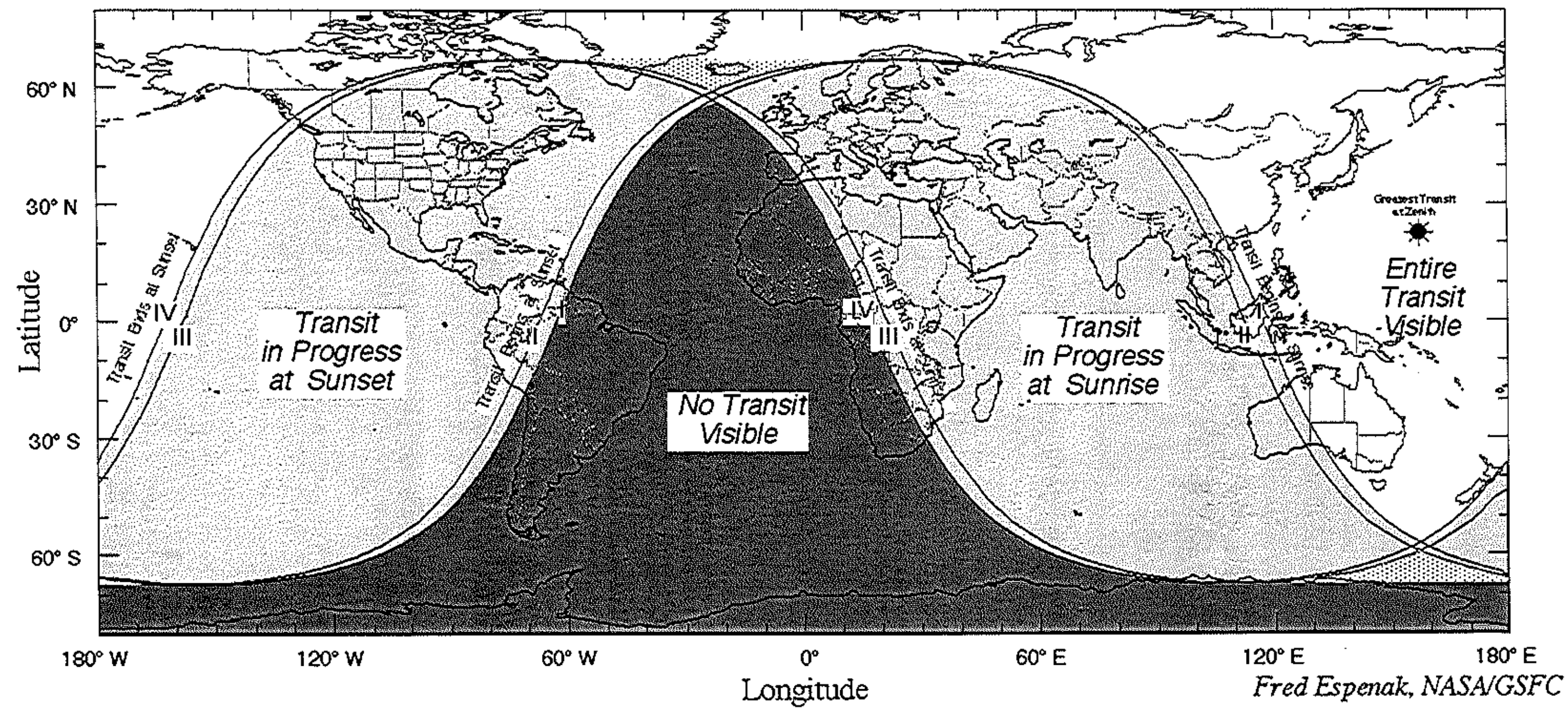


Figure 3 - World Visibility of the Transit of Venus — 2012 June 06

Astronomy 17 Final Review

Blackbody Planck Spectrum:

An opaque object of a particular temperature emits a particular spectrum, which is set by thermal equilibrium. The energy emitted at a given frequency is described by

$$\frac{dE}{d\nu} = \frac{2h\nu^3}{c^2}\frac{1}{\exp(h\nu/kT) - 1}$$

The peak of the curve is given by Wien's Displacement Law:

$$\lambda_{\rm peak}T = 2.9 \text{ mm K}$$

Flux and Magnitudes:

The flux of an object is given by

$$F = \frac{L}{4\pi d^2}$$

The apparent magnitude of a object is given by

$$m = -2.5\log_{10}\left(\frac{f}{f_0}\right)$$

From this we can derive an expression for the absolute magnitude:

$$M = m - 5\log_{10}\left(\frac{d}{10 \text{ pc}}\right)$$

Note: The brighter an object, the smaller its magnitude!

Angular Resolution:

The angular resolution of a telescope is given by

$$\theta = 1.2\frac{\lambda}{D}$$

Doppler Shift:

The general expression for a non-relativistic Doppler shift is

$$\lambda_{\rm obs} = \lambda_0\left(1 + \frac{v}{c}\right)$$

The general expression for redshift is

$$z = \frac{\lambda_{\rm obs} - \lambda_0}{\lambda_0} = \frac{\lambda_{\rm obs}}{\lambda_0} - 1$$

Angular Scale:

If an object is a distance d away and has a radius of r, we can easily compute the angular scale it subtends on the sky:

$$\theta = 2\tan^{-1}\left(\frac{r}{d}\right)$$

Parallax:

One way to measure distances to objects is using parallax. The parallax distance is defined as

$$D(\text{pc}) = \frac{1}{\theta('')}$$

Stellar Populations:

Population I stars have [Fe/H] of about 0 and are located in the thin disk. Population II stars have [Fe/H] of less than -1 and are found in the halo or the thick disk. The definition of metallicity is

$$[Fe/H] = \log_{10}\left[\frac{n_{\rm Fe}/n_{\rm H}}{n_{\rm Fe,\odot}/n_{\rm H,\odot}}\right]$$

Distance Ladder:

Below is an illustration of the 'Distance Ladder' in Astronomy:

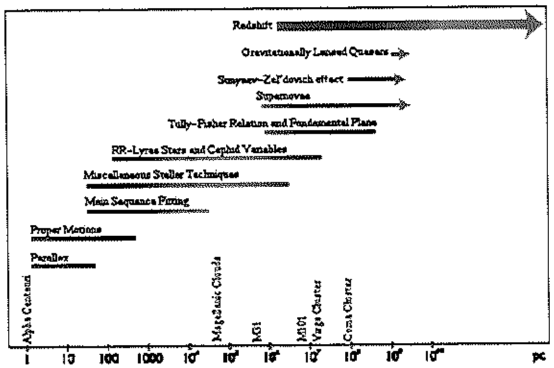


Figure 3.2: *The different distance estimators. This seemingly simple plot shows a grand overview of our efforts to measure distances in the Universe. Adapted from [Rowan-Robinson, 1985] and [Roth and Primack, 1996].*

Galaxy Rotation Curves:

You should know how to find the circular velocity of a galaxy given a density profile $\rho(r)$. For example, evaluate $v_c(r)$ given $\rho(r) = \frac{C}{4\pi r^2}$. Start by computing the mass as a function of radius.

Galaxy Scaling Relations:

The circular velocity of a spiral galaxy is given by:

$$v_c = \sqrt{\frac{GM(<R)}{R}}$$

The Tully-Fisher Relation gives a relationship between luminosity and circular velocity for spiral galaxies:

$$L \propto v_c^4$$

The Faber-Jackson Relation gives a relation between luminosity and velocity dispersion for elliptical galaxies:

$$L \propto \sigma^4$$

Finally, the Fundamental-Plane gives a relation between surface brightness, velocity dispersion, and effective radius for elliptical galaxies:

$$R_e \propto \sigma^{1.24} I_e^{-0.82},$$

where

$$I_e = \frac{L}{2\pi R_e^2}$$

Schwarzschild Radius:

The Schwarzschild radius is defined as the distance from the center of an object such that, if all the mass of that object were compressed within a sphere of that radius, the escape speed from the surface would be equal to the speed of light. We can derive that simply:

Schechter Function:

The number of galaxies with luminosities between L and $L + dL$ is given by

$$\frac{dN}{dL} = \phi(L)$$

Here, $\phi(L)$ is the Schechter function.

$$\phi(L) = \phi_* \left(\frac{L}{L_*}\right)^{\alpha} e^{-L/L_*} \frac{dL}{L_*}$$

The total number of galaxies in the luminosity range L_1 to L_2 is just found by integrating:

$$N = \int_{L_1}^{L_2} dN = \int_{L_1}^{L_2} \phi(L) dL$$

Where to Download Mathematica

Go to the Harvard University Information Technology website:

http://www.fas-it.fas.harvard.edu/fasemailtools/

Select **Software Downloads** and then click on **Mathematica**.

Note: It takes awhile for the download to complete. And, you'll need to wait a bit to receive the Activation Key. You have to type in the Activiation Key once you receive it in order to be able to run the software.

Top Ten Most Useful Commands in Mathematica

1) The Documentation Center

Help → Documentation Center → Search for any command!

2) Evaluate an Expression

(4*π/3)*50∧2
Press [Shift + Enter] → Always use this to execute any command!

3) Taking a Derivative

D[x∧(5/2), x]

4) Integrating

Integrate[1/x, x]
Integrate[1/x, {x,1,5}]
Note: In Mathematica, Log[x] is base e. Log10[x] is base 10.

5) Plot a Function

Plot[x∧2, {x, -10, 10}, AxesLabel → {"x", "f(x)"}]

6) Simplify an Expression

Simplify[$\frac{1}{(3(1+x))} - \frac{(-1+2x)}{(6(1-x+x\wedge 2))} + \frac{2}{(3(1+1/3(-1+2x)\wedge 2))}$]
FullSimplify[ ] can handle a wider range of tasks.

7) Define a Function

f[t_] := (4/3)*t∧6

8) Solve an Equation

Solve[x∧2 + a*x + 1 == 0, x] → Gives exact solutions
NSolve[x∧2 + 3*x + 1 == 0, x] → Gives approximate numerical solutions

9) Clear Variables

Clear[x]
Note: Once you define a variable in Mathematica, it keeps that value until you clear it.

10) Find a Series Expansion

Series[Exp[x], x, 0, 10]

Compiled by: Meredith MacGregor, 2012

Astronomy 302

"Scientists Teaching Science"

Spring 2013

Course Objectives (from the Syllabus):

1. Develop an understanding of the cognitive perspective of teaching science, how growth in scientific conceptualization is a non-linear, paradigmatic, process
2. Learn about, practice, and reflect upon the many skills and techniques that aid in college teaching
3. Gain an understanding of the research literature and professional support relevant to teaching in science
4. Produce a professional teaching portfolio to aid in documentation and growth as a college educator.

Philosophy of the Course (from the Syllabus):

The process of learning to be an effective teacher of college students is not a simple matter of adding additional experiences and knowledge to the ideas with which you begin. Having been a student for years led you to identify your own preferences; some teaching methods work better or worse than others. Yet, your observations about your own learning rarely transfer with any utility to others. You will find that your students can be quite different from you. The process of growing as a teacher requires reconstructing your conceptualization of teaching and learning. To this end, you must consider the ideas and principles with which we grapple both inside and outside of class and reconcile them with your prior views.

This course has a cognitive emphasis. There has been an enormous research effort over that last twenty-five years to identify the stages and barriers to learning science. This course will familiarize you with this research and expose you to the cognitive foundations of how students learn science concepts. This course also provides an opportunity to reflect on your past experiences in science classrooms, exposes you to a variety of teaching activities, and helps you learn from readings dealing with some of the nuts and bolts of teaching science. You will have many opportunities to brainstorm solutions to common problems and to help you develop your own unique techniques and style of teaching.

The pedagogy used in this class attempts to model some of the practices for the teaching of science at the college level. Being put into situations that make you feel like an undergraduate again can be unnerving to some. You may feel like you are being exposed to new ideas using methods that you have moved beyond in your adult life. This exposure to simpler, more emotionally engaging methods is purposeful. It is not enough to lecture about teaching methods that work. It is much better to learn new concepts and skills

through pedagogies in which you are immersed, generating the same feeling, confusions, successes, and difficulties that your own students will endure. I have found that instructors rarely adopt new techniques that they have not experienced themselves and from which they learned something valuable. This includes cooperative learning, alternative assessment, student presentations, hands-on learning, concept mapping, affective activities, computer simulation, and conceptual change models of teaching. Familiarity breeds utilization. As William Byrd said in 1611, "The song is best esteemed with which are ears are most acquainted."

Assignments Included Here:

1. Assignment C: Misconceptions Interview Paper
    - Conduct an interview with two non-experts on light and color
    - Write-up the results and analyze apparent misconceptions
2. Assignment D: Confusion
    - Write a short paper that addresses student confusion
3. Assignment E: A Teaching Retrospective
    - Interview a teacher who has figured prominently in your growth and development as a scientist because of their teaching
    - Summarize the results of the interview and interpret them in the context of your own teaching experiences
4. Assignment F: Course Philosophy
    - Design an introductory science course primarily for non-majors
    - Develop the course philosophy and goals
    - Discuss how you might monitor and assess the achievement of these goals
5. Assignment I: Lesson Plan
    - Assemble a lesson plan from existing materials found in textbooks, supplementary materials, and teaching journals
6. Assignment J: Questioning
    - Observe a class and record the questions asked both by the students and by the teacher
    - Analyze the questioning in the classroom from different perspectives
    - Consider how the questions fit into Bloom's Taxonomy
7. Assignment L: Test Item Characteristics
    - Design an assessment with both multiple choice and short answer questions
    - Give your test to a range of subjects and analyze the difficulty and discrimination of each question

Meredith MacGregor

Astronomy 302

19 February 2013

Assignment C: Misconceptions Interview Paper

Throughout the first few weeks of the course we have spent considerable time discussing student understanding of light and color along with interviews as a way to probe that conceptual understanding. In order to become more familiar with these ideas, we were asked to conduct our own interviews concerning light and color with two non-experts on the subject.

Interview Content and Methods

I chose to center my interview on the unique properties of a fluorescent piece of plastic. Since fluorescence is an advanced concept, I did not expect the subjects to be able to provide a complete explanation of the phenomenon. Instead, I was looking to probe the subjects' understanding of light and color by asking them to predict the outcome of several small experiments given their previous knowledge. In order to make the subjects more comfortable with the interview before launching into a discussion of the fluorescent plastic, I began each interview by asking a series of questions concerning vision and ultraviolet radiation. Most of these questions were motivated by the questionnaire included in Libarkin et al. (2011) or those asked of students in *Minds of Our Own* (1997). A full list of the questions I initially planned to ask is included at the end of the paper. However, as the interviews progressed, I ended up altering many of these questions in an attempt to tailor the questions to fit the previous responses of the subjects.

My two interview subjects had quite dissimilar backgrounds. The first subject was a 23-year-old female college graduate. The second subject was a 61-year-old female who completed some college. Both subjects pursue careers outside of the sciences and both subjects have not taken a physics course since they were in high school.

A Brief Review of the Interview Process

We have discussed a number of interview techniques in class. While conducting my two interviews, I tried to incorporate as many of these strategies as I could. I found it very helpful to begin the interviews with some general questions (i.e. 'When was the last time you took a physics class?'), followed by a few simpler questions about light and color, and culminating with a set of predictive questions. This allowed the subjects to adjust to the tone and feel of the interview and avoided putting them on the defensive at the beginning. However, despite these efforts, there was a marked difference in the enthusiasm of the two subjects. I am sure that this issue could be helped if the subjects were not acquainted with the interviewer from the start. A continued relationship with the interviewer pre-/post- interview makes the subject much more conscious of his or her answers and the potential concern of being judged if an answer is incorrect. The other technique I found most helpful was having objects available for the subjects to interact with. Even when asking a question about what one might be able to see in a completely dark room, having actual objects on the table to consider made the question much more tactile and real to the subjects. Slightly abridged transcripts of both interviews are attached at the end of the paper.

General Misconceptions of Light and Color

With such a small sample size and a limited number of questions, it is difficult to draw any significant conclusions concerning trends in people's understanding of light and color. On many of the questions asked, the two subjects gave very dissimilar answers. The first subject answered all of the questions concerning sight by referring to a previous experience caving several years ago. While in the cave, the subject observed that wintergreen lifesavers glowed white when chewed in the dark. As a result, the subject believed that white paper, because of its color, would also be visible in a dark room. This belief is similar to the conclusions drawn in Libarkin et al. (2011): "Explanations provided on questionnaires for the visibility of white paper relied most heavily on the color of paper." Perhaps most striking was the fact that when this same subject was asked to explain whether or not she would be able to see the paper immediately or after sometime, she replied that without a light source your pupils might not dilate at all and thus, you might not be able to see anything. This answer directly contradicts her previous statement that she would be able to see the white paper and therefore represents an incomplete understanding of the process of vision. In fact, this one experience in a cave affected many of this subject's answers. At the end, she stated that the plastic must glow because of the same reason the wintergreen lifesavers glowed in the dark. The second subject showed no misunderstanding of this topic and simply stated that she would not be able to see anything because there was no light in the room.

However, despite these difference, there were two common misconceptions that were striking: (1) a view of light as a mixing of colors and (2) an incomplete understanding of ultraviolet radiation. At several times during both interviews, the subjects made references to mixing colors of light. Many predictions of what would happen when colored cellophane was placed over colored plastic involved some mention of the resulting perceived color. A similar view of mixing colors was also discussed in class several times. While both subjects recognized the term 'ultraviolet (UV) radiation' and provided some definition of it, neither expressed a completely clear view. The second subject described UV light entirely within the context of the Sun, a trend that is also evident in the work by Libarkin et al. (2011). Both subjects had difficulty deciding what the wavelength of UV light was in relation to the visible spectrum, indicating that while they might understand that UV radiation is invisible to the human eye, they do not grasp its place in the electromagnetic spectrum.

The Predictive Interview Technique

We have had several lively discussions in class concerning what technique is best used to assess students' knowledge of a subject. After completing this project, I am more firmly convinced that asking students to make predictions is a particularly effective way of probing misconceptions. Fluorescence is not a concept that would be covered in any introductory class that a non-science major might have taken. Thus, I did not expect any of my subjects to respond to my questions with a complete and accurate description of the phenomenon. I must admit that initially I was not sure what I would be able to conclude from the series of questions concerning the plastic, beyond how my subjects use scientific reasoning to approach a question. However, I discovered that asking the subjects to make predictions about the plastic allowed me to probe their understanding of colors, filters, and wavelengths of light much more thoroughly than by simply asking them to define those terms. When the first subject was asked to define 'a filter,' she responded with the correct idea that a filter only lets certain wavelengths of light through. However, the same subject still showed a misunderstanding of how filters truly work by predicting that colors would mix together when one color of plastic is placed on top of another color of plastic.

I did notice two potential complications to this technique of assessing student knowledge. First, it was easy for the subjects to get derailed from the ideas of light and color and focus in on simple observations of how the plastic was scratched or looked when you pressed your hand against it. Both subjects spent a significant period of time considering how the plastic looked when you pressed different objects against it and ignored the fact that the plastic glowed on the edges instead of the front and back faces of the panel. It was difficult as an interviewer to guide the discussion back onto the topic at hand without leading the subject to a specific conclusion. In addition, when I initially wrote the questions for the interview, I spent no time considering what order to show the different pieces of cellophane in. However, when I actually conducted the interviews, I changed this order and that change seems to have affected the responses of the subjects somewhat. Showing the red cellophane before the blue led the subjects to predict that the blue would also stop the plastic from glowing. When that turned out not to be the case, the subjects spent more considering this observation and proposed more theories or possible outcomes for the subsequent questions. Furthermore, both subjects referred to ideas they had mentioned in the first half of the interview when considering the fluorescent plastic (wintergreen light savers and UV radiation). This raises a potential flag in my mind as to how much you bias subject responses by conducting an interview of this type in a specific order.

Implications for Teaching Students

Several responses from my two subjects surprised me. I was genuinely taken aback that both of my subjects viewed light in terms of 'colors' instead of 'wavelengths' and thought that colors would mix together as if they were paint. In retrospect, I can see how this viewpoint might arise from a combination of seeing a spectrum in science class and working with the same colors in a physical form through art. The literature we have discussed in class backs up this result—students in science classes seem to struggle with the concept of color (Driver, p. 131-132). Additionally, both of my subjects showed an incomplete or inaccurate understanding of UV radiation. This potentially stems from the fact that 'invisible' light does not fit well into a 'color-centric' view of radiation. I find these conclusions of particular interest since I frequently have to teach about colors, filters, and UV radiation in astronomy classes. In the future, I will not assume a complete understanding of these concepts and hope to come up with some way of clarifying these ideas further for my students.

Sources

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. 1994, *Making Sense of Secondary Science* (Routledge)

Libarkin, J. C., Asghar, A., Crockett, C., & Sadler, P. 2011, AER, 10, 010105-1, 10.3847/AER2011022

Schneps, M. H. & Sadler, P. M. 1997, *Minds of Our Own* (Harvard-Smithsonian Center for Astrophysics)

Light and Color Interview- Subject #1

Abbreviated Transcript

MM: When was the last time you took a physics course?

I1: Actual physics... Probably high school. Senior year. I took AP Physics, though. I got a 5 on the non-calculus exam!

MM: Have you ever been in a completely dark room?

I1: Does a cave count?

MM: A cave... By completely dark room, we're talking about a room with no ambient light.

I1: OK, then yes.

MM: Imagine that we are in a room that is a mile under the ground with lead walls and no lights and no power whatsoever. Will you be able to see any of the objects on the table (banana, dime, white paper)?

I1: I'm thinking back to my experience with the cave and I remember... Can I go on and on about my caving experience?

MM: Yes of course!

I1: I remember the cool thing that we did when we turned out our head lamps in the cave was we had some wintergreen lifesavers with us and you put them in your mouths and your mouths glow.

MM: I have done that. That is awesome.

I1: So, I'm thinking that maybe the white paper you would be able to see. But, I'm not sure.

MM: Do you think that you'd be able to see it immediately or would it take time to see it?

I1: Well, I'm thinking on the one hand when you're in a very dark room but there's some light, your pupils will dilate and will adjust to the light... or the darkness. And, you'll be able to see things better. But, when there's no light source, I don't know whether your pupils would dilate or you just wouldn't be able to see anything at all.

MM: Shifting slightly, have you ever heard of ultraviolet radiation?

I1: Sure.

MM: Taking AP Physics, I would assume that you have. What does UV light mean to you? If you were to define that term to another person?

I1: Well, it's on the spectrum. I always forget whether it's longer waves or shorter waves. I'm thinking it's shorter waves than the visual light spectrum. But, it's a little bit beyond what we can see.

MM: Imagine we are back in the same completely dark room, but now a single lamp that only emits ultraviolet radiation illuminates it. We have the same three objects. Will you be able to see any of the objects on the table?

I1: I'm thinking of the things that they stamp on your hand at Chuck E. Cheese's that they put under UV light and then you can see it. But, on the other hand, you're not supposed to be able to see UV light... So, I would say that it won't make a difference because it is not in the visible light spectrum.

MM: OK, great. Now... This is a piece of plexiglass that my professor brought into class last week and I thought was awesome... First of all, what observations can you make about this piece of plastic? If you could just look at it and describe it.

I1: There's something in it that makes it seem to glow when things are against its surface. So, the edges seem to be glowing and when I put my fingers on it they also sort of turn it this lighter shade of green. I'm just investigating.

MM: Investigate away... I also have a piece of black construction paper. What do you think will happen if I take this piece of construction paper and put it on top of the piece of plastic. Do you think the piece of plastic will look the same? Will anything change about it?

I1: Well... can I make predictions of possibilities? ... It's possible that the whole face could light up. I don't know whether the lighting up is caused by something dark on the other side or it's caused by being touched.

MM: Do you think anything will happen to the edges?

I1: I don't know. But, I think that it will only glow if you put the black paper against it... When I'm looking at the black paper through the plexiglass.

MM: Let's try doing this first... If I put the paper on top of the plexiglass.

I1: Wow. The edges stopped glowing! Weird!

MM: Something changed! I haven't actually tried pushing it up against it. Does that do anything?

I1: No, it doesn't. But, the edges glow from this direction when you look at it.

MM: I also have a few other things. One, is this piece of orange plastic.

I1: It doesn't seem to glow in the same way. Although, I'm not sure if that's because it is a darker shade of plexiglass or whether it's because there's some quality about it that's different.

MM: What do you think will happen if we put the piece of orange plastic on top of the piece of green plastic?

I1: Well, I can predict again that the green plastic will glow. Or, it might make the orange plexiglass seem lighter. Or, it could make the orange plexiglass glow.

MM: Let's try it.

I1: Now, neither of them glow. Interesting. I keep not predicting...

MM: That's ok! ... I also have a few pieces of colored cellophane. What happens if you hold the piece of blue cellophane up to the ceiling light and look through it?

I1: Well, I think the ceiling light will look blue.

MM: Why is that?

I1: Well, because I'm looking at the ceiling light through a blue filter.

MM: And, what do you mean by a filter?

I1: The idea is that... I'm just going off on a limb here. It blocks out all colors that aren't some shade of blue.

MM: What do you think will happen when we put the blue cellophane on top of the green plastic?

I1: Judging by what's happened in the past, I think it will stop glowing.

MM: Ok. Let's try it.

I1: It continues to glow. Apparently.

MM: I also have green cellophane. What do you think will happen with the green?

I1: Probably a similar thing to the blue.

MM: Do you want to try it?

I1: Well, now it looks like it's not glowing... Glowing less.

MM: Ok, finally, I have red cellophane. What do you think this cellophane will do?

I1: Well, since the red plastic made it stop glowing, maybe it will also make it stop glowing ... And, it glows less.

MM: Do you have any ideas why different pieces of cellophane have different effects?

I1: Well, if it has anything to do with different waves of color, then I would guess that different waves of color would react in different ways and make it look different.

MM: Lastly, I have a few pictures that I printed off. It might be a bit of a stretch, since I don't have these objects, but these are rocks and test tubes. Do you notice any similarities between them and this piece of plexiglass? Can you make any comparisons?

I1: They seem to also have a glow.

MM: If someone told you that all of these different things were glowing for the same reason, what would you say to them? Do you think that's possible?

I1: They're probably glowing for the same reason that the wintergreen lifesavers were glowing. And, I can't tell you why the wintergreen lifesavers are glowing. Some special property…

MM: Do wintergreen lifesavers glow this color?

I1: Well, they're more sort of a white.

Light and Color Interview- Subject #2

Abbreviated Transcript

MM: Have you ever been in a completely dark room?

I2: No.

MM: Imagine that we are in a room that is a mile under the ground with lead walls and no lights and no power whatsoever. Will you be able to see any of the objects on the table (banana, dime, white paper)?

I2: No.

MM: Can you explain why?

I2: Because there's no light.

MM: What does the term UV radiation mean to you?

I2: Ultraviolet

MM: Can you explain a bit more?

I2: It's rays from the Sun. And, they cause sunburn.

MM: Does UV light have a long wavelength or a short wavelength?

I2: I haven't got a clue. They must be long, since they come from the Sun.

MM: If we are in the same completely dark room underground, but there is now a lamp that emits UV radiation, will we be able to see any of the three objects from before?

I2: I don't know enough about UV radiation to say.

MM: My professor brought this piece of plastic to class ... It's a piece of plexiglass. If I give this to you, what's your initial impression of it? Can you describe it?

I2: It's plastic. It's a green-yellow color.

MM: Anything else about it?

I2: It's scratched.

MM: Is it dull?

I2: It's kind of shiny. It glows. It glows where my hand is.

MM: Does it glow if you just look through it? Or does it just glow if you put your hand against it?

I2: It glows on all of the edges, regardless of whether or not I put my hands on it.

MM: I also have a piece of black construction paper that I'm going to put on top of the plastic. What do you think will happen?

I2: It will still glow.

MM: What happened?

I2: They seem to be glowing less.

MM: In addition to that, I have a few other things, including this other piece of plastic.

I2: It's orange.

MM: Do you notice anything else about it?

I2: It doesn't glow.

MM: What do you think will happen if I put the orange piece of plastic on top of the green piece of plastic?

I2: It will turn a lighter shade of orange.

MM: What do you notice?

I2: It's not glowing so brightly on the edges.

MM: I also have a couple of pieces of cellophane. What do you think will happen if I put the green cellophane over the plastic?

I2: It will make it dark green ... It dulls the edges a bit.

MM: What about red cellophane?

I2: What color will that make? It will change colors but it will still glow ... No, it doesn't glow.

MM: I have one more color of cellophane- blue cellophane.

I2: It will still glow. It will turn it purple ... Yes, it still glows!

MM: Do you have any ideas why different pieces of cellophane have different effects?

I2: It has to do with the four colors.

MM: What do you think the cellophane might be doing when I put it over the plastic?

I2: Blocking the ultraviolet.

MM: Lastly, I have a few pictures that I printed off. It might be a bit of a stretch, since I don't have these objects, but these are rocks and test tubes. If someone told you that all of these different things were glowing for the same reason, what would you say to them? Do you think that's possible?

I2: Sure.

Light and Color Interview Questions

1. Have you ever been in a completely dark room?
2. Imagine that we are in a room that is a mile under the ground with lead walls and no lights. Will you be able to see any of the objects on the table (banana, dime, white paper)?
3. Can you explain your answer?
4. (How long do you think it will take your eyes to adjust?)
5. Have you heard of UV radiation?
6. What does this term mean to you?
7. Imagine we are back in the same completely dark room, but now a single lamp that only emits ultraviolet radiation illuminates it. Will you be able to see any of the objects on the table?
8. My professor brought this fascinating piece of plexiglass into class last week. So, I borrowed it and want to see what other people think about it. Can you tell me your initial impression (observations) of the plexiglass.
9. What do you think will happen if I cover the top of the plexiglass with black construction paper?
10. I also brought some colored cellophane with me. What will happen if I cover it with green cellophane?
11. Red cellophane?
12. Blue cellophane?
13. Why do you think that happens? Why do you think the plastic looks different when these different pieces of cellophane are placed over it?
14. Show a picture of fluorescent material. Can you make any observations of these materials? How do they compare to the plastic?
15. Some people say that chemicals are responsible for this effect in both materials. What do you think of that idea?

Meredith MacGregor

Astronomy 302

26 February 2013

Assignment D: Confusion

As a freshman in college, I took a course at Harvard titled "The Darwinian Revolution." Taught within the History of Science department, the course examined the intellectual structure and social context of evolutionary ideas throughout the 19th and 20th centuries. I remember vividly being asked to read an article for the course that had been taken from *Science* and was titled "Public Acceptance of Evolution." While reading the article I was confronted with the plot included at the end of this paper. Never had I seen such a graphic representation of how the United States truly compared to the rest of the world in terms of public belief of evolution. The United States falls below Japan and thirty-two other European countries when it comes to the percentage of the population that accepts evolution as true. Having always believed that the United States was a leader in scientific research and education, I was floored to see those statistics and immediately began to ponder the underlying issue. Are American students not being well educated in evolutionary concepts? Is this result indicative of larger underlying flaws in science education? The list of questions raised by such a result is lengthy. What is clear to me is that in order for the United States to maintain its standing in the world as a leader in science and technology, something must be done to reverse this lack of scientific understanding. And, it seems that the best way to tackle this problem is to address the difficulties and failings in science education.

Abigail Lipson writes in her article that "confusion seems to be a hallmark of the undergraduate science experience, especially for students in introductory courses" (Lipson 2002). Having taken my fair share of science courses, this statement certainly rings true in my experience. The last time I took a biology course was in high school. In all honesty, I do not have many memories of being confused in my AP Biology course. Sitting here now, I chalk that up to one (or more) of three reasons: (1) I have selectively blocked those moments of confusion from my mind, (2) the amount of material covered in biology in a large public high school in Colorado was not so vast as to be particularly challenging, or (3) my biology class always seemed much easier compared to the physics course I was taking concurrently. I am inclined to choose option (3) as the most likely reason for my rosy high school biology course memories. Yet, if high school physics was confusing at times, it pales in comparison to the ordeal that was college physics.

I was a physics major in college and so took a large number of physics courses. For the most part, I enjoyed taking these courses. They were a fair amount of work, but I felt that I learned quite a bit and they were applicable to what I wanted to study in graduate school. However, I only reached this place of 'physics clarity' after surviving my freshman mechanics course. I had always been successful in science classes in high school, which made the whole experience even more jarring. Never had I been so confused in a course. Every week featured two long lectures in which equations were thrown on the board with little explanation or context. Barely had I finished copying down one derivation before another even more complicated one appeared on the next board over. This was then followed by weekly problem sets that took somewhere on the order of ten plus hours to complete and exams that required me to assimilate the information that seemed to be flying at me a mile a minute. I was certainly suffering from a case of 'cognitive overload' as described by Lipson. In the end, it took most of the semester for me to take control of my confusion and use it to restructure my study habits in order to be more successful in such an environment. Now, looking back on the experience, I have concluded that college physics is often taught with a 'trial by fire' method. The introductory classes are designed to weed out the weak in an almost Darwinian approach to education. My freshman mechanics course had nearly one hundred people in it, while my sophomore quantum mechanics course had only thirty. It seems that most current college physics professors went through a similar ordeal in their undergraduate and graduate education and now feel that it is there obligation to perpetuate the cycle: "the tendency is to continue to teach as we were taught" (Alters 2002). However, I am unconvinced that this cycle should be carried on. Did I really learn as much as I could have from classes taught in this way? The answer is almost certainly 'no.' An even more thought provoking question might be whether or not it is actually to the advantage of the field to dwindle the numbers of physics majors in college so drastically.

Now, as a teaching fellow for two of the introductory astronomy courses at Harvard, I am confronted with confusion in my own students. I have encountered several students, who attend lectures and complete all of the problem sets successfully, but have a difficult time performing on the exams. They are able to finish the problems on the assignments by executing a series of steps that they are taught in lecture and office hours, but they are unable to solve similar problems on exams. Instead of learning and understanding the concepts behind the problems, these students have simply memorized a cookbook routine necessary for success in a given situation. When they cannot use that routine, they are at a loss as to how to approach a problem. As Lipson (2002) puts it so eloquently: "They can have all of the component materials—a repertoire of useful operations and a catalogue of relevant information—and yet not know where to begin, what is applicable, or how to proceed." Not only is this situation frustrating for all parties involved, students and teachers, it also does nothing to help the students learn to think critically. In order to better train students to pursue scientific careers, we must try and find ways to more effectively communicate science in order to avoid this situation.

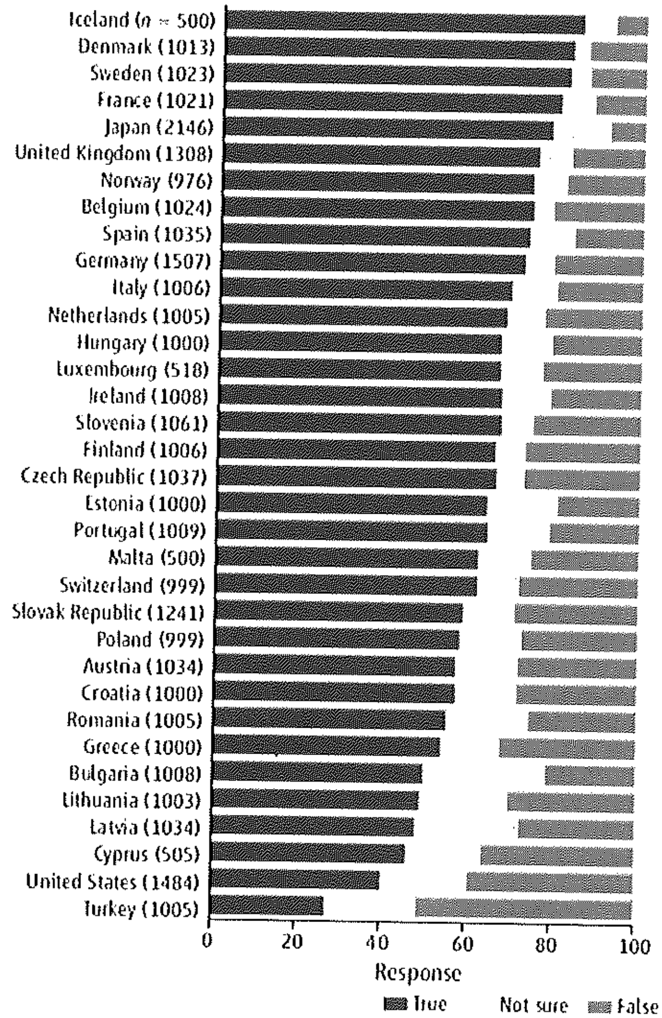
Alters and Nelson present two 'major complications' to teaching evolution in introductory college biology: (1) the need teachers feel to cover a pre-specified amount of material and (2) the impact of religious beliefs. For the most part, college introductory science courses have been offered in nearly the same form for year after year. A clearly laid out syllabus details all of the topics the course will cover that are considered to be pre-requisite knowledge for all of the upper level courses in the department. Each professor that teaches the course steps through this required content in the same way as it has been covered in the past. However, Alters and Nelson make an excellent point that "it is far better to decrease the content in order to increase long-term understanding" (Alters & Nelson 2002). What good does it do students to see all of this material if they only remember a small fraction of it? If they do not remember the concepts they will not be able to use them in upper level courses whether they were introduced to them or not. It is much more likely that students will succeed in more difficult courses if they take the time to truly learn a few essential concepts. I think that this complication is universal to college introductory science courses. Students learning physics will also be better served by mastering a smaller set of essentials than struggling with an overload of information.

The second complication addresses the fact that many students (~90% according to Alters & Nelson) enter introductory biology classes with a set of religious beliefs. Since evolutionary theory is in direct conflict with Christian religious doctrine, this naturally produces a tension between a student's prior beliefs and the new material that they are being asked to assimilate. This is certainly a significant complication for teaching evolution in college. However, I do not believe that this is the most significant complication encountered when trying to teach electricity or physics in general. In other areas of science, I think that this concern can be generalized to prior misconceptions of all forms. Alters and Nelson also address this at length in their article: "Unless students actively examine their initial conceptions and compare them to standard formulations, the initial conceptions are likely to remain unchanged and may often even distort any related new material that is learned." This is true for previously held religious beliefs as well as for previous experiences, theories, and teachings. Religious misconceptions are very prominent in the teaching of evolution, because organized religious groups are vocal about expressing these views. Yet, other misconceptions can be just as detrimental to student learning in the long run if not addressed.

Up until this point, we have considered mainly how misconceptions and different lecturing styles affect how well a student is able to cope with new information presented in a course. However, it is also important to consider that the information presented might inherently be flawed. What a teacher communicates to his or her students will certainly be colored by his or her own beliefs, views about, and knowledge of the subject. We need only to look back to the original plot to become concerned about teachers' knowledge of evolution. Statistically speaking, if less than 40% of Americans think that evolution is true, some significant fraction of teachers must be in the 60% that are undecided or think that it is false. Rutledge and Mitchell conducted a survey of Indiana public high school biology teachers concerning their education background and views on evolution and present the results in their paper. I have reworked their plots to include percentages instead of just total numbers and included them at the end of this paper. These tables show a clear correlation between the number of credit hours in biology taken by teachers and teacher acceptance of evolutionary theory. Of teachers that have taken less than 24 credit hours in such courses, only 12% view evolution as true. That percentage is increased to 68% for teachers who have taken over 40 credit hours in biology, a significant improvement. It is important to note that only 83 teachers fall into the first grouping, with 271 in the second. Still, the result is significant. In addition, teacher completion of a course in evolution or a course in the nature of science also correlates with an increase in acceptance of evolutionary theory. In both cases, the percentage of teachers who accept evolution increases from about 60% to 80%

with the completion of such a course. It is interesting to consider the results from Table 2. While the teachers surveyed may not have a taken course specifically concerning evolution, they still show an increase in acceptance of evolutionary theory. It seems that simply being more knowledgeable in biology as a scientific field has a net positive impact on their understanding of evolution. This is not entirely a surprising result. Taking more science courses exposes one to more opportunities to think critically about science. As a result, teachers will be more able to draw their own conclusions about evolution and be able to overcome previous misconceptions they might have had. While there is not a similarly controversial issue in physics courses, I think that the trend in teacher effectiveness compared with teacher course-taking in the field still applies. The more familiar a teacher is with a subject, the more able they will be to distill it in an understandable manner for their students.

It is clear that the United States lags behind much of the world in the public understanding and acceptance of evolution. However, the problem is larger than simply this one statistic. Science education in the United States is not as effective as it could be. In order to correct this issue and maintain the American international scientific standing, we need to seriously consider what the underlying complications are for students learning science and how to remedy those issues. From the sources presented in this paper, we can conclude that several of the most pressing complications are the style of lecturing in American universities, student misconceptions, and teacher preparedness and understanding of scientific conflicts. High schools, colleges and universities should consider carefully how best to address these and other potential education complications. Once we identify the reasons students have difficulty learning science, it will be much easier to construct a strategy to remedy them.



Public acceptance of evolution in 34 countries, 2005.

Taken from Miller et al. (2006)

Tables taken from Rutledge and Mitchell (2002)

Table 2:

Teacher credit hours earned in biology versus teacher acceptance of evolutionary theory

	No		Undecided		Yes		
	Number	Fraction	Number	Fraction	Number	Fraction	Total Number
Less than 24	52	0.63	21	0.25	10	0.12	83
25-40	45	0.23	67	0.34	86	0.43	198
Over 40	38	0.14	50	0.18	183	0.68	271

Table 3:

Teacher completion of a course in evolution versus teacher acceptance of evolutionary theory

	No		Undecided		Yes		
	Number	Fraction	Number	Fraction	Number	Fraction	Total Number
Yes	16	0.09	17	0.10	139	0.81	172
No	97	0.26	50	0.13	232	0.61	379

Table 4:

Teacher completion of a course in the nature of science versus teacher acceptance of evolutionary theory

	No		Undecided		Yes		
	Number	Fraction	Number	Fraction	Number	Fraction	Total Number
Yes	19	0.10	14	0.08	150	0.82	183
No	94	0.25	53	0.14	222	0.60	369

Sources:

Alters, B. J., & Nelson, C. E. (2002). Perspective: Teaching evolution in higher education. *Evolution*, 56(10), 1891-1901.

Lipson, A. (1992). The confused student in introductory science. *College Teaching*, 40(3), 91-95.

Miller, J. D., Scott, E. C., & Okamoto, S. (2006) Public Acceptance of Evolution. *Science*, 313, 765.

Rutledge, M. L., & Mitchell, M. A. (2002). High school biology teachers' knowledge structure, acceptance & teaching of evolution. *The American Biology Teacher*, 64(1), 21-28.

Meredith MacGregor

Astronomy 302

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Assignment E: A Teaching Retrospective

At the start of college, I was fully committed to pursuing a degree in physics. It was only after a full semester of coursework that I realized that I might want to study something slightly more applied. In the end, two introductory astronomy courses were enough to convince me that astrophysics was the path to choose. The first course I took was taught by John Huchra and provided a sweeping overview of stellar, planetary, galactic, and extragalactic astrophysics. The second course was taught by Edo Berger and was an introduction to observational methods in astrophysics. At the end of taking those two classes, I was certain that I wanted to continue with astronomy in my ultimate career. Since Edo Berger subsequently became my undergraduate thesis advisor and because his course had such a profound effect on my decision to pursue astrophysics, I decided that he was an ideal person to interview for this assignment.

Edo Berger had little to no training for teaching prior to being hired as a junior faculty member at Harvard. He completed his graduate studies at Caltech. There, second year students served as teaching assistants for the first year graduate courses. Outside of holding office hours and writing up problem set solutions, there was no opportunity to practice delivering a lecture. I found this statement particularly surprising, because it stands in stark contrast to the situation here at Harvard. In order to receive a Ph.D. in astrophysics at Harvard, every graduate student is required to teach two full semesters. In my mind, this is a reasonable requirement. Those graduate students who go onto careers in academia will have to teach to some extent. It is best for those students to have experience while in graduate school, so that they do not have their first experience teaching as young faculty hires. It seems that the Harvard astronomy department recognizes this and thus places some value on teaching. This made it all the more surprising for me to hear Edo's response to a later question: "Here, teaching is not even part of the evaluation when people get hired. When I applied here, I didn't have to supply a teaching statement or give a sample lecture…I was hired based on my research." A discussion of this seems particularly apropos, since the department is currently looking to hire a new junior faculty member. As graduate students, we have taken great care to investigate each candidate's teaching experience and philosophy. It is disconcerting to think that the department might not have ever asked these same questions of the candidates. Is there truly a disjoint between the values of the department in choosing a faculty hire and the values of the students?

Another interesting topic of discussion was how to go about teaching a new class. Edo described taking a step back from the material and considering carefully what he wants his students to take away from the course, what key concepts and ideas should they be exposed to. In that context, he discussed introducing students to "the nomenclature and language that comes with astronomy." Astronomy does have a truly staggering amount of confusing terminology and symbols. In my own experience, I have found that many students struggle to get past this initial barrier of confusion in order to begin to actually understand the concepts that the symbols represent. As Abigail Lipson writes, "...students find them too opaque and have to repeatedly parse the symbol into its components in order to make sense of it. Then once they have the symbol all nicely parsed, they find the information itself too unwieldy to be of use in solving the problem at hand" (Lipson, 2002). I certainly agree with Edo that tailoring lectures to make this terminology more clear is a valuable teaching method. However, in the same answer, Edo also described exposing students to a wide range of material without necessarily worrying if they understand all of it fully. That way, he argues, the students will have at least seen the material and will have an easier time handling it when they encounter it again in a later course. I remain unconvinced that this is the best approach to take when teaching a course. If the students do not fully understand the material, are they really going to be able to recognize it later on in another class? It seems to me that teaching students material they do not comprehend is not productive. It would be far better to teach them a smaller number of concepts that they truly understand. Such an approach gives them a much more secure basis of knowledge to build off of in their later studies and coursework.

It was clear from our conversation, however, that Edo has spent considerable time considering the best ways to teach effectively. He commented extensively on how ineffective simply lecturing students can be. His alternative teaching style is to continuously ask students questions (this brings to mind the Socratic style of teaching common in a number of courses), which he claims engages students more and "makes them feel like they are actually part of the process." However, Edo does acknowledge that some students do not enjoy this style of teaching. Listening to Edo describe his teaching style raised a number of questions and ideas in my mind. It is interesting to consider whether or not there is an effective method of teaching that all students will enjoy and learn from. Or, perhaps the process of deciding on a teaching philosophy is simply a process of determining what teaching method is most effective and enjoyable for the largest majority of students. Given the wide range of ways in which students learn material best, is it even possible to find a teaching style that works for all people?

Despite my quibbles above, I am in complete agreement with Edo on several points. Edo spent some time describing the experience of giving a lecture that does not go well. He describes the feeling associated with such an experience as "…a sense of failure—someone depended on you and you let them down." In my own experience as a teaching fellow, I can concur that it is a horrible feeling to realize that your students did not understand what you said in a lecture or did poorly on an exam despite your best efforts. It is particularly unsettling and unsatisfying to explain a concept to a student and have them not comprehend the material any better when you have finished. It makes you question your entire approach to answering the question in the first place. Edo also discussed the role of enthusiasm in teaching. Oftentimes, people assume that the professors who are most enthusiastic about teaching are the best at it. However, quality of teaching and general excitement about a subject are not necessarily correlated: "…it wasn't just that some professors were lazy. Some of them were incredibly enthusiastic about teaching, but they still did a really terrible job." I think that perhaps enthusiasm improves your lectures if you are already skilled at communicating a subject clearly. Without a clear lecturing style, however, enthusiasm may make your lecturing more entertaining, but it will not help you communicate any more effectively to your students.

Overall, I found my discussion with Edo Berger to be very interesting. He mentioned several things that I do not fully agree with. However, overall, I think that he made a number of excellent points. Having professors who think about the quality of their teaching can only benefit students in the long run. Departments should value teaching more and professors (and graduate students) should take advantage of the resources that are available to them in order to develop their teaching abilities.

Lipson, A. (1992). The confused student in introductory science. *College Teaching*, 40(3), 91-95.

Assignement E:

Abbreviated Transcript of Interview with Edo Berger

What (if any) training did you receive for teaching?

So, I had no training at all for teaching. When I was in grad school at Caltech, we were essentially the TAs in the second year for the first year grad courses. Essentially that meant office hours and putting together problem set solutions and things like that, but there was no actual teaching involved. So, I never actually stood in front of a class until I came here. The first day of classes was my first day in front of a class. So, yeah, it's very different from here where you guys get exposed to teaching and there are lots of opportunities to deliver lectures and se what it's like.

How do you prepare to teach a new class?

So, step one is... I kinda step back and think what are the concepts I want to deliver to the students. What do I think are the main important ideas that they need to understand and the material they should be exposed to. Even if not all of it immediately sinks in that they've at least seen it. I've found personally that's been useful for me that I actually go back and look at notes from grad school that there are things that I did not really fully understand at the time that I understand much better now, but they're there. So, at least they didn't seem like completely foreign concepts when you see them the second time or the third time or hear them in a talk. So, I come up with that list of ideas that I think are central. And, part of it is not just introducing the concepts in the context of physics, but the nomenclature and the language that comes with Astronomy so that when... I always think about when the student goes to a colloquium what would they need to know so that they can be immersed in the talk. When I taught high energy, one of things that I went over was the classification of AGN and supernovae and things like that so that people are aware. And then once I have that list, I kinda go through and build each lecture along those guidelines. And, what I've found over time is that sometimes the first time you deliver that lecture you try to cover too much material. You have to step back a little bit and try to synthesize that to the real core concepts and not worry about every detail. That's it. I try not to practice things too much. It's my own personal preference. I feel that that actually allows discussion to flow more kind of as a back and forth. Rather than delivering a well-polished thing that if you get it interrupted in the middle you can lose track of what you were doing. I think that that has worked reasonably well so far.

Did you have a particular epiphany about teaching? Did your revelations come from your own personal failure or success?

The first epiphany I had about teaching is that when it doesn't go well, it feels really terrible. And, it feels terrible in a different way from research not going well, getting scooped on a paper or something. It's a sense of a failure—someone depended on you and you let them down. And, so the first time I had that feeling was kind of an epiphany on teaching for me and I vowed to myself 'never again.' It still happens once in awhile where you feel like, well, you know, this didn't go as well or the students weren't fully engaged or didn't fully follow the material. So, you go through, and think maybe I should drop this bit of information, it's just adding more confusion than clarity. So, I think that was sort of my first epiphany. Because, again, I did not have any experience with teaching going in. I didn't really know what to expect. I kind of assumed that it's something that you want to take seriously, but maybe it doesn't require that much effort. Most of it is material that I know. But, it turns out that giving a bad lecture is a terrible experience. And, the other one that I found really useful is that standing in front of the class and just lecturing at them doesn't seem to work as effectively as trying to constantly ask questions. That seems to engage the students a lot more. It makes them feel like they are actually part of the process. Some students don't like it very much but others like the opportunity to show they actually understand the material. And, it also makes the students feel more comfortable to ask. That always seems to be a barrier. You look at a class and everyone is clearly confused but nobody wants to say anything. If you kind of engage them they feel more comfortable that they are allowed to ask questions. They don't feel bad. So, that's an effective tool. And, I think that if I had had any training that's something they would teach you on day one. It's not like I discovered anything fundamental, but it was nice to kind of figure it out.

What lessons have you learned from teaching that have been particularly useful? Are there books, articles, or workshops that you have found helpful?

No, it's kind of been mainly trial and error, which is probably the worst way to do this, because this is not a new thing that everyone needs to invent on their own. There's a lot of literature. And, I think that the Bok Center, provides a valuable resource- it's mainly geared at teaching fellows, but also for faculty. They will actually sit down with you and evaluate your teaching. I've never looked into it. And, there's also never been any real evaluation from the department itself. Nobody has ever popped into my class and seen how I give a lecture and talked about how to improve that, which would probably be a useful thing, probably somewhat intimidating, but also useful to have feedback. So, I think the main feedback I've had is from talking to students and the teaching evaluations, which so far have been positive. It would be nice if there was more formal training, especially early on, with faculty as they come into the department or university- a kind of crash course. One thing I definitely feel is that as you do it more and more you get more set in your ways, right, and it becomes harder to tell someone they've been teaching the wrong way for years. It's best to catch them on day one before they do any damage to the students. I think that to a large extent from talking to other faculty that it's very much a personal thing.

Some people thing that teaching is something they have to dispense with and that it's a distraction from research and some people feel that it's really a passion that they want to devote more time to. There are these two extremes and it's a personal choice where you fall. It definitely can take an infinite amount of time. I'm sure you've noticed that. Even Journal Club takes up a few hours each week. Overall, I find it extremely enjoyable, which is something I did not expect. I came in with mixed thinking about teaching, it could be fun but it could also be a strain on my time, but it turned out to be enjoyable.

What is the best class that you have ever taught and why? And, the worst?

In the time that I've been here, I've taught two courses. I taught Astronomy 100, which used to be Astro 97, and including this semester, I think I've taught that four times. And, then, I taught High Energy, a high energy astrophysics course. And, those are very different. Both because the content, the material is very different. One class is much more hands on and the other is much more theoretical. So, I found the high energy course to be much more challenging for me as a teacher. Really, I had to go back and update my knowledge about the field prior to teaching the course. So, that was extremely productive, because I work in high energy astrophysics. But, it also was very time consuming. But, in any case, that was a fun course. Observational methods is fun in a very different way, because I feel like it's my opportunity to expose students for the first time to what astronomy is really like. And, then, I feel like I'm in a privileged position that I get to show them how much fun actual research is and that as undergrads they can actually participate, actually do meaningful, interesting things. Not just repeat some experiment that somebody did three hundred years ago, but participate in research, write a paper. So, that's an enormous amount of fun and very rewarding in a different way than teaching a graduate course. So in that context, my experience has been overall very positive. There's no class that I didn't enjoy teaching. Except for as I mentioned at the very beginning, a few lectures here and there where you feel like things are not going well.

What do you wish you has known about teaching before entering the classroom? What advice would you give to a younger self?

I think that one thing is to actually try to take advantage of the knowledge that exists in the community. To some extent, because I had no experience going in, I also wasn't fully aware of the range of material that could have been available to me, things like the Bok Center, the education department here. I felt that it was my responsibility to figure this out on my own and it worked fine, but it's not the right approach. You end up spending a lot of time on things that have already been done. So, I think that's key. And, perhaps that's something that departments should do. Part of the packet that you get when you come in should also include something about here are the resources that are available at the university or the CfA for teaching. Generally, I think it varies from one university to another. Here, teaching is not even part of the evaluation when people get hired. When I applied here, I didn't have to supply a teaching statement or give a sample lecture.

Teaching never came up as a topic at all. I was hired based on my research. And, I could have ended up being a terrible teacher or a great teacher. That was not part of the discussion. And, it's different at a lot of other places. A lot of liberal arts colleges, that's much more about teaching.

Did you have a role model? Someone whose teaching you admired?

Not in a really direct way. As I've been here, I've never really sat in on lectures by other faculty. But, you see people in other teaching environments, giving a talk or Journal Club or things like that. And, you kind of see whose style you like and which style is effective. And, there are some people who seem much more natural and have a very clear way of delivering a talk. So, I think for me, one of the people that I've always thought was a great teacher was Ramesh. I've actually asked him about it and I think he had an experience similar to mine. He never did anything formal. He just kind of went into it and he's been a good teacher. And, I think that some of it is talent in delivering the material and really synthesizing it down to its essentials, but a lot of that is experience. But, my own personal experience, in grad school, with one exception, the teaching was fairly poor. And, it's funny, because it never correlated with- it wasn't just that some professors were lazy. Some of them were incredibly enthusiastic about teaching, but they still did a really terrible job. And, I don't know whether they just didn't know how to do it or never got any useful feedback. But, that was something kind of eye-opening, you can be excited, but still be a terrible teacher. But, I had one or two who were fantastic, and who in some respect should have just taught all of the courses

Assignment F: Course Philosophy

My Proposed Course and Why I Want To Teach It

- An introductory astronomy course with historical perspectives
- Discussed in class how it is important for students to understand the historical context of science—the history of scientific discovery and revolution
- Students of science rarely study the history of science—important to read outside of the field
- I took two history of science courses in college
- I also took several interdisciplinary courses—interesting to see the interplay between two subjects
- Worked at the Maria Mitchell Observatory

My Course Goals

- To introduce students to a broad sweep of astrophysics by employing basic physics
- To make informed order-of-magnitude calculations.
- To develop an understanding of how different forces have shaped astrophysical ideas historically
- To develop a historical sensibility about scientific knowledge and ways of knowing

Motivation For Those Goals

- Went back and looked at the syllabi for my previous courses, for courses I have TFed for, and for other introductory astronomy courses in the department.
- Those goals are cobbled together from some of the introductory courses and my previous history of science courses.
- One goal that stuck out: "the never-ending and greatest detective story ever told, with evidence always the arbiter" (Irwin Shapiro)

Possible Topics to Cover

- Astronomy with interesting history
- Cepheids
- Planetary dynamics
- HR diagrams, stellar evolution

- Extragalactic Astronomy (Shapley-Curtis Debate)
- Expanding Universe, Cosmology

Possible Course Materials

- Original documents (read Galileo's original papers in History of Science 100)
- Books like *Miss Leavitt's Stars*

Possible Assessments

- Exams (to assess the scientific aspects)
- Possible labs or independent research project or both? → Chance for the students to work independently and synthesize the course material
- Problem Sets
- Clickers? (Not entirely sure how effective these are... depends on the class size)

Possible Challenges

- Finding the right balance between science and historical content
- Don't want the students to have double the work... How much reading, how many problem sets, etc.

Meredith MacGregor

2 April 2013

Astronomy 302

Assignment I: Lesson Plan

A Reading Assignment:

- Selections from Chapter 3 of an online Astronomy textbook (Chris Impey, 2012):

www.teachastronomy.com

- This textbook is interactive and can be viewed in 'chapter format' or 'Wikimap format.' This formatting allows students to interact with the book however works best for them to understand the material. (See screenshots to get a better feel for how this works!)

Simulations and Demos:

- Found several very helpful online simulations that show how Kepler's Laws work and allow students to change system parameters:

Astronomy Education at the University of Nebraska-Lincoln:

http://astro.unl.edu/naap/pos/animations/kepler.html

McGraw-Hill:

http://highered.mcgraw-hill.com/sites/0072482621/student_view0/interactives.html#

- A screenshot of the first simulation is included in the attached material.
- I also found a clever demo described by Alex Filippenko that shows students what would happen to the Earth if the Sun's gravity were suddenly cut off. This particular demo and lots of other fun demos and labs are included in the following book:

Pompea, Stephen M. *Great Ideas for Teaching Astronomy*. Pacific Grove, CA: Brooks/Cole Thomson Learning, 2000.

Assignment:

- The online textbook used above for the reading assignment also has homework questions that I think are particularly interesting and well posed. In order to create a problem set, I would plan on taking some subset of these questions that pertain to the topics I want to emphasize most.

Meredith MacGregor

Astronomy 302

16 April 2013

Assignment J: Questioning

Preface

Since I was out of town for the entire week prior to the deadline of this assignment, I had to think creatively about how best to complete it remotely. My Hawaiian location made it difficult to actually attend a class in person. However, several universities have started posting public lecture videos of their courses. I was fortunate enough to find several online lecture videos for an introductory course on thermodynamics offered at MIT. While this may not have been the original intent of the assignment, I feel like I have obtained a unique perspective through this exercise. By watching the video of the lecture online, I was able to examine the body language of the professor and the exact wording of questions more closely than I would have been able to do while attending the lecture in person. Hopefully this provides a complementary perspective to the observations of my colleagues in Astronomy 302.

Analysis

Overall, it was quite interesting to watch this lecture video. In many ways, this class reminds me of the majority of physics courses that I took in college. The professor asks questions that the students hesitatingly respond to. Oftentimes, the students do not truly understand the material, but they are too concerned about appearances to ask clarifying questions. Their lack of understanding is then made apparent when the professor poses a difficult problem that few people in the class can answer. In such a class scenario, questioning is certainly not being used effectively. However, this class did have a few notable differences from this standard pattern—some effective and some less so.

One telling moment in class came when the professor posed a conceptual problem to the class. After drawing a diagram of a process on the board, the professor asked if the process was reversible. Since the question asked students to apply what they had learned in the lecture previously to a new situation, this question falls into the category of 'Application' in Bloom's

Taxonomy. After explaining the problem and giving the students a few minutes to think, the professor polled the class. Many students were hesitant to commit to an answer. So, the professor then rephrased his expectations: "All right, I'm going to give you ten seconds, fifteen seconds to make up your mind. You're not allowed to be on the fence here…you can talk to your neighbors, you know, do a little bit of thinking." After some time had passed, the professor posed the question again and asked students to vote. This time, the entire class participated. The professor then proceeded to present and explain the correct answer thoroughly. Although this was not a formal exercise, it reminded me a bit of the idea of 'ConcepTests' discussed in Chapter 8 of *Handbook of College Science Teaching* (2006) and outlined as follows: (1) Question posed, (2) Students given time to think, (3) Students record individual answers, (4) Students convince their neighbors, (5) Students record revised answer, (6) Feedback to instructor: Tally of answers, and (7) Explanation of correct answer.

However, there were several things about this implementation that I thought could have been done more effectively. First of all, the class did not seem to participate fully in the exercise. During the supposed discussion time, very few students actually talked to one another. Perhaps if this questioning technique was more formally incorporated into the class and the professor's expectation made clear, students would feel more compelled to participate. Or, perhaps the students had never had such an exercise in this class before. Having only seen one lecture, I am not sure if the professor used this technique frequently. In addition, at the end of the second vote, the students had clearly reached the wrong answer. While the professor did explain the correct answer in the end, his initial response to the students was quite negative. In fact, he almost had a tone of sarcasm and disbelief: "Good thing physics doesn't work on the rule of the majority, otherwise we'd be in big trouble. Wow, let's walk through that." I think that it would be much more constructive for the professor to respond slightly differently. He might instead ask the students what their reasoning was in an attempt to figure out where their misconceptions were. Simply polling students does not give a clear view of their understanding without including additional probing at the end of the exercise. Furthermore, adopting an encouraging tone will make students more likely to participate fully in the future. When a professor adopts a critical tone, the students will surely feel that they are being judged. Such a dynamic is not desirable if the students are to get the most out of taking the class.

While the previous example discussed indicates a higher level of questioning in the course, the professor's questioning was as a whole at a much more basic level. Throughout the entirety of the lecture, the professor posed a continuous stream of rhetorical questions. Oftentimes, the professor asked a question and then paused for a split second before answering it himself. Other times, the professor asked a question that was simply a statement with 'right?' added on the end. A few examples are included below:

- "This is already branded into your brain, right?"
- "What is the pressure at? One atmosphere, one bar."
- "The temperature rises when the pressure drops, right?"

None of these questions open up any opportunity for further discussion. Indeed, all of these questions are contrary to the questioning techniques described in Chapter 12 of *Tools for Teaching* (2009). By using such rhetorical questions, professors might be searching for a nod of agreement from students to check for understanding without disrupting the flow of their lectures. However, such question do not truly probe student understanding at any level. Even if a student does answer affirmatively, you have not actually learned anything more about that student's true understanding of the subject at hand. Most likely, you have simply learned that that student is eager to gain the approval of the professor and appear as if they have a complete understanding of the subject.

The general dynamics of the lecture, including student questioning, were also interesting to observe. The professor was clearly enthusiastic about the subject and seemed to be well prepared. All of the questions he asked appeared to have been thought of and planned out beforehand. However, given the enthusiasm of the professor and his attempts to motivate some discussion, I was a bit surprised by the general lack of engagement on the part of the students. Only one student asked a question of the professor during the entire lecture. It was difficult to hear the actual question, but the professor's response was very brief. It is important to note that the student who did ask a question was sitting towards the back of the room, so there did not seem to be any bias towards sitting at the front versus the back in terms of participation. In order to truly judge the student-posed questions, though, it would be necessary to observe several more lectures.

It certainly appears that this class might be improved by changing the questioning dynamic. Furthermore, I do not think that such a change would be difficult to make. Currently, the professor asks few questions that truly engage the students and evaluate their understanding. As a result, the students are hesitant to participate in any discussion when they are asked such a question. Thus, an easy change for the professor to make would be to simply ask more questions that encourage student-student interaction and that require students to demonstrate their understanding of the lecture material. If such a dynamic is set up early in the course, students will expect such questions and grow more comfortable with presenting their ideas to their peers and to the professor. Along the same lines, the professor should consider changing the way he reacts towards student questions and answers. Several times during the lecture, the professor read over a paper while waiting for a student response. And, when the student vote returned the wrong answer, the professor dramatically crossed out the response on the board. These actions indicate impatience and will most likely discourage student participation. The professor should instead communicate an air of interest, encouragement, and expectation. While these are small tweaks to make to a class, they would go a long way to making questioning a much more integral part of lectures and would benefit both the students and the professor in the long run. The students would ultimately feel more in control of their learning and would not hesitate to ask clarifying questions. This increased student participation would then allow the professor to better evaluate his students' learning. An improved class questioning dynamic would ultimately lead to a better class for all involved.

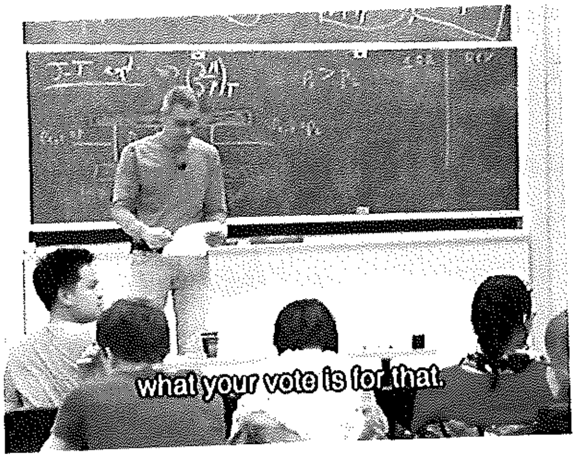
Sources

Davis, Barbara Gross. *Tools for Teaching*. San Francisco, CA: John Wiley & Sons, Inc., 2009.

Mintzes, Joel J. & William H. Leonard, eds. *Handbook of College Science Teaching*. Arlington, VA: NSTA Press, 2006.

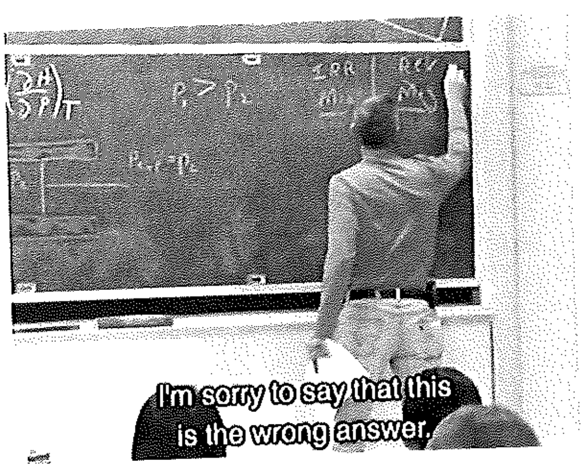
Photos

To better illustrate some of the above points, I took several screen shots of the lecture. These are included with captions below.



The professor poses a question and then reads over a paper while waiting for student responses.

The professor asks students to raise their hand and vote on a question. The students are hesitant to participate.



The professor crosses out the incorrect student response on the board.

MIT Course 5.60: Thermodynamics and Kinetics

Spring 2008, Prof. Moungi Bawendi

Lecture 4: Enthalpy

PROFESSOR BAWENDI: When I flail my arms around I generate work and heat. This is not a constant volume process. If I'm the system, what's constant when I do this? Anybody have an idea? What's the one function of state? I'm the system, the rest are the surrounding. What's the one function of state that's constant when I'm doing all my chemical reactions to move my arms around? Temperature?

STUDENT: Pressure?

PROFESSOR BAWENDI: Pressure, right. Pressure is constant. What is the pressure at? One atmosphere, one bar. So the most interesting processes are the processes where pressure is constant. When I had have a vial on bench top, and I do a chemical reaction in the vial, and it's open to the atmosphere, the pressure is constant at one atmosphere. When you've got your cells growing in your petri dish, the pressure is constant at one atmosphere, even if they're evolving gas, pressure is constant.

...

PROFESSOR BAWENDI: You're boiling water or whatever, you want to know how much heat do you need to boil that amount of water under constant pressure?

...

PROFESSOR BAWENDI: OK, so this is the kind of, this is the kind of concept that needs to be branded into your brain, so that if I come into your bedroom in the middle of the night and I whisper to you delta H, you know, you should wake up and say q p, right?

...

PROFESSOR BAWENDI: OK, so last time you looked at -- any questions on this first? Yes.

STUDENT: [INAUDIBLE] from the T delta V to the delta p here? What was the reasoning behind that?

PROFESSOR BAWENDI: p is constant here. It's constant pressure. OK, so now, last time you looked at the Joule expansion to teach you how to relate derivatives like du/dV. du/dV under constant temperature. du/dT under constant volume. You use the Joule expansion to find these quantities. Now these quantities were useful because you could relate them. The slope of changes, with respect to volume or temperature of the energy with respect to quantities that you understood, that you could measure. We're going to do the same thing here.

...

PROFESSOR BAWENDI: If I keep the pressure constant. I change the temperature, what does that mean? What is dH/dT? If I keep the temperature constant, and just change the pressure, dH is going to change, but how is it going to change? What does this mean in terms of something I can physically understand? That's the program now for the next few minutes. What are these quantities? What is dH/dT as a function, keeping pressure constant, what is dH/dp, keeping temperature constant? All right, let's start with the first one, dH/dT, keeping the pressure constant.

...

PROFESSOR BAWENDI: So for reversible process, constant pressure, what do we know? This is already branded in your brain, right? Reversible process, constant pressure dH=dq. So we can write that down, dH=dq, constant pressure. That's by definition of enthalpy. That's why we created enthalpy. What else do we know?

...

PROFESSOR BAWENDI: OK, so now we have the other one, dH/dp constant temperature. How do we relate this to something physical? Well, it's going to be an experiment, very much like the Joule experiment.

...

PROFESSOR BAWENDI: OK, the Joule-Thomson experiment. This is going to get us dH/dp constant temperature. What is this experiment? You take a throttle valve, which consists of some sort of porous plug between two cylinders that is insulated.

...

PROFESSOR BAWENDI: You got the picture here? Any questions on that? (pause) All right, then as I push through, I'm going to start with all of my gas on this side, and at the end, I'm going to have all the gas on the other side. Let me first ask you this, is this a reversible or in irreversible process? Right, let me add one more piece of data here which I said in words, but which is actually important to write down before doing the problem. Is this a reverse -- any guesses?

PROFESSOR BAWENDI: How many people vote for that this is a reversible process? I've got one vote back there, two votes, three votes, four votes. Anybody else? How many people think this is irreversible? It's about a tie, and everybody else doesn't now. All right, I'm going to give you ten seconds, fifteen seconds to make up your mind. You're not allowed to be on the fence here. You've got to decide, all right? This is, you can talk to your neighbors, you know, do a little bit of thinking. And I'm going to give you ten seconds to figure this out, what your vote is for that.

PROFESSOR BAWENDI: All right, let's try again. How many people vote that this is reversible? That looks like a majority to me. Irreversible? Let's look at the show of hands? All right, so this is the majority here. Good thing physics doesn't work on the rule of the majority, otherwise we'd be in big trouble. Wow, let's walk through that.

PROFESSOR BAWENDI: I'm sorry to say that this is the wrong answer. OK, why is that the wrong answer? Well, just think, you know, think about it.

...

PROFESSOR BAWENDI: OK, important -- if you are part of this group here, think about it and make sure you understand that. All right, so this is the experiment. Now what are we doing with that? The initial state, let's look at what we are doing.

...

PROFESSOR BAWENDI: OK, so let's go through this and see what we would do which is to calculate the heat and the work. This is well insulated. So, what is the -- let's do the first one here. What's q for this process here? Anybody?

STUDENT Zero.

PROFESSOR BAWENDI: Zero, right. This is an adiabatic process. It's well insulated. Heat is not going in or out, adiabatic. q is equal to zero. So all we need to find out is the work now. Let's divide it up into the two sides, the work going on on the left hand side, my left hand side or your left hand side, and the work going on on the right hand side. So let's first look at the left hand side.

...

PROFESSOR BAWENDI: All right, what is delta u? Delta u is q plus w. q is zero. Delta u is just w.

...

PROFESSOR BAWENDI: For that experiment, the constraint, so we need a constraint here, right, we need a constraint here. Right? We need a constraint here.

...

PROFESSOR BAWENDI: OK, so we're going to see this using a Van der Waal's gas. Let's look at a Van der Waal's gas and see what happens in the Van der Waal's gas. Any questions, first? What we've been talking about, the Joule-Thomson experiment, constant enthalpy process?

...

PROFESSOR BAWENDI: I want to cool a gas with a Joule-Thomson experiment, what temperature do I have to be at?

...

PROFESSOR BAWENDI: So that means that if you compress something it's going to cool. The temperature rises when the pressure drops, right? Or in this case here, if I do my Joule experiment delta p is negative, p2 is less than p1, that means that delta T is positive, right? So in this experiment here, this side is going to heat up.

...

PROFESSOR BAWENDI: So you have to do it in stages. You take your room temperature liquid helium, and you cool it with liquid nitrogen to 77 degrees Kelvin, the new, you're not quite there yet, unfortunately right?

...

PROFESSOR BAWENDI: So that's what you do when you make liquid helium. All right, any questions on this lecture or any of the concepts that we talked about?

Meredith MacGregor

Astronomy 302

30 April 2013

Assignment L: Test Item Characteristics

The Questions

The questions for this quiz were designed to test participants' understanding of topics that might be covered in an introductory astronomy course. In order to better determine participants' true understanding of the concepts being tested, the possible answer choices for each question contain at least one common misconception. For example, one question asked was 'How often is the Sun directly overhead in Boston?' Included in the possible answer choices are 'Every day,' 'Only during the summer,' and 'Only on the summer solstice.' We discussed in class earlier in the semester how a common misconception from popular culture is that the Sun passes directly overhead everyday at all locations on Earth. Even if people understand that the Sun is lower in the sky during the winter, they often believe that it at least passes directly overhead in the summer months. Special care was taken to ensure that the correct answer and misconception answers had similar wording and tone. This was done to avoid having participants choose an answer simply because it used more jargon than other possibilities. A list of all questions asked is attached at the end of this paper.

Several of my questions were based off of misconceptions that we discussed multiple times early in the course (height of the Sun in the sky, seasons, phases of the Moon). Thus, I expected many of my survey participants to fall prey to these same misconceptions. I also included two questions about the orbit of the Moon around the Earth and about its own axis. I must admit that I expected people to do very well on these questions, since those properties of the Moon are easily observed from Earth. Finally, I included a question about scaling within the Solar System. I had no real expectations for this question, since I was unsure how familiar most people are with astronomical distances.

Survey Logistics

In order to improve my later analysis, I tried to get as many survey participants as was reasonable given the time constraint. Initially, I simply posted the survey on Facebook. This approach worked reasonably well, garnering about 50 participants. Subsequently, I posted the survey on Reddit. This increased the number of participants to 183 and broadened the population of survey participants outside of college and graduate students. In the end, 102 men and 76 women (5 participants listed other) completed the survey. The most well represented age bracket was 18-30. However, I did have participants in each possible age bracket (18 and under, 30-50, and 50+). Histograms of both of these distributions are attached. I also included several questions about education level, previous coursework in astronomy, and general interest in astronomy as part of the survey. However, as of yet, I have not had time to sift through all of the data to draw any meaningful conclusions about the resulting statistics. Something to come back to in the future perhaps!

The last piece of logistics was determining how to score each question. This was straightforward for the multiple-choice questions, but quite a bit trickier in the case of the short answer. For the short answer, I asked 'What is the Sun mainly composed of?' I hoped that this question would get at whether or not participants understood that the Sun is in fact a star and what that entails in terms of physical composition. For the final scoring rubric, I gave two points for a completely correct answer that mentioned hydrogen. I gave one point for discussing gas or plasma and zero points for anything unrelated. A complete list of all short answer responses is attached. For the most part, participants did fairly well with this question and mentioned something that earned them at least one point. The completely wrong answers included (but were not limited to) 'fire,' 'magma,' and 'orange juice.'

Survey Results

With 183 participants, I was able to get a fairly clear idea of each question's difficulty and discrimination. A good starting place when analyzing test questions is the difficulty or 'p-value.' Below, is a table listing the calculated p-value for each item:

	# Correct	Percentage
Q1	89	0.49
Q2	55	0.30
Q3	150	0.82
Q4	100	0.55
Q5	35	0.19
Q6	133	0.73
Short Ans.	136	0.74

It is clear that these seven questions span a range of difficulties. Question 5 (concerning Solar System scalings) was by far the most difficult for all participants, as I anticipated. Many people chose the largest answer possible, most likely playing into the view that astronomical distances are typically vast. I was a bit surprised to see that Question 2 (seasons) was the second most missed question. This question addressed a common misconception that the reason it gets warmer in the summer is *directly* due to the fact that one hemisphere is tilted closer to the Sun, so the result is not entirely shocking. However, my Facebook friend group is quite biased towards well-educated people who have an interest in science. I would have expected more of them to understand this concept. The easiest question turned out to be Question 3 (the time it takes the Moon to go around the Earth). Of the people who did get this question wrong, though, the vast majority chose 'One day.' This answer also plays into a common misconception; from the perspective of someone on Earth, the Moon does appear to complete a full orbit every day.

Another useful statistic is the item discrimination or 'd-value.' In class we discussed calculating this for the lower and upper half of participant scores. However, since I had enough data, I chose to calculate this for each total score (1 through 8). For each individual question, I calculated the percentage of people who received a given total score *and* answered that question correctly. A plot of the results of this analysis is attached (percentage of people who answered each question correctly versus their total score). The same analysis was completed for the short answer question and is attached separately. A question is considered most discriminating if it has a sharp slope. By this metric, Question 5 is clearly the most discriminating. For a total sore of 1-7, not more than 30% of people got the question correct. Only people who received a perfect score on the entire survey answered this question correctly. From above, the 'p-value' for this question is 0.19. Thus, this item is both difficult and discriminating. The least discriminating question is Question 3, which also has the highest 'p-value.' For total scores of 2 or above, at least 50% of people answered this question correctly.

It is interesting to note that for Question 6, there is a significant drop in the percentage of people who answered the question correctly between those who got a total score of 1 and those who got a total score of 2, 17% and 7%, respectively. In 'Psychometric Models of Student Conceptions in Science,' Philip Sadler discusses how instruction can actually strengthen preference for certain misconceptions. Sadler proposes that 'such ideas may actually be markers of progress toward scientific understanding' (Sadler 1998). I do not have nearly adequate statistics in this survey to draw any such conclusions. However, since similar trends have been observed before, it would be interesting to investigate this further.

A quick glance at the plot of percentage correct versus total score reveals that none of the item curves have quite the same slope. Instead, they seem evenly distributed between less discriminating (Questions 3 and 6) and more discriminating (Questions 2 and 5). The curve for each question turns over and starts to rise at a different total survey score. It seems to me that this is a good way to structure a test if you want to end up with a normal distribution. All of the students will get a few of the questions right. Then, as the question difficulty increases, fewer and fewer students will get the question right. For the hardest questions, only the very top students will answer them correctly. In order to consider this idea further, I created a histogram of total test score. Indeed, the resulting distribution (plot attached) looks roughly Gaussian. The peak occurs at a total score of 4 and falls off fairly symmetrically towards scores of 1 and 8.

Discussion of the Results

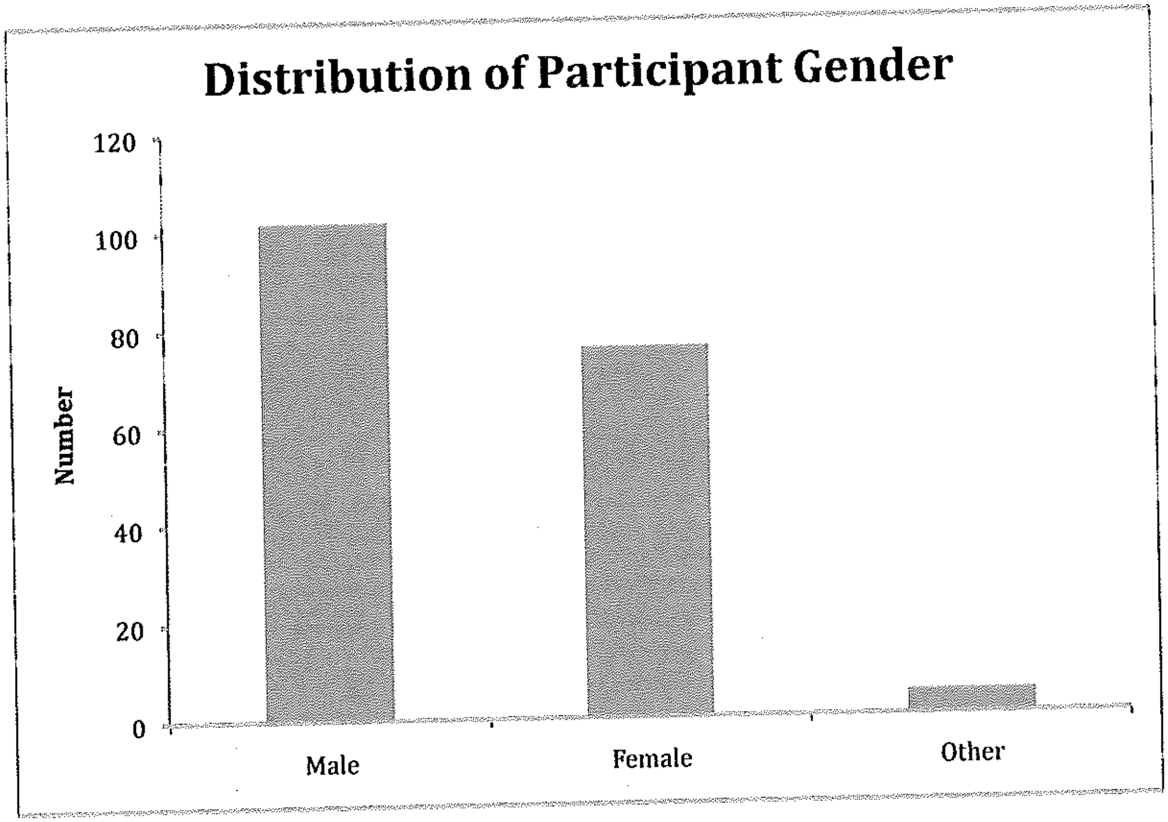
It took much longer than anticipated to come up with good multiple-choice items for this survey. In creating these questions, I tried to make sure that the possible answers for each question included several misconceptions. Oftentimes, students will simply select whatever answer on a test seems most likely to be correct. This selection might be made because a particular answer is longer or includes more technical terms. Thus, I tried to make all possible answers for each question equally appealing. All of the answers are of a similar length and use the same vocabulary. However, creating such test questions was challenging. In Question 2, for example, I tried to avoid making any mention of angle of incidence or direct/indirect rays, by phrasing the correct choice to be 'The Sun is higher in the sky.' I felt that this answer encapsulated the concept well without including any jargon. After seeing some of the comments on Reddit, though, it seems that some people might have been misled by the simplicity of this answer. On the other hand, if a person is misled so easily, it might be indicative of the fact that they do not truly understand the concept in the first place. The majority of people who answered this question incorrectly chose 'The northern hemisphere is closer to the Sun,' which does not completely explain why it is warmer in the summer.

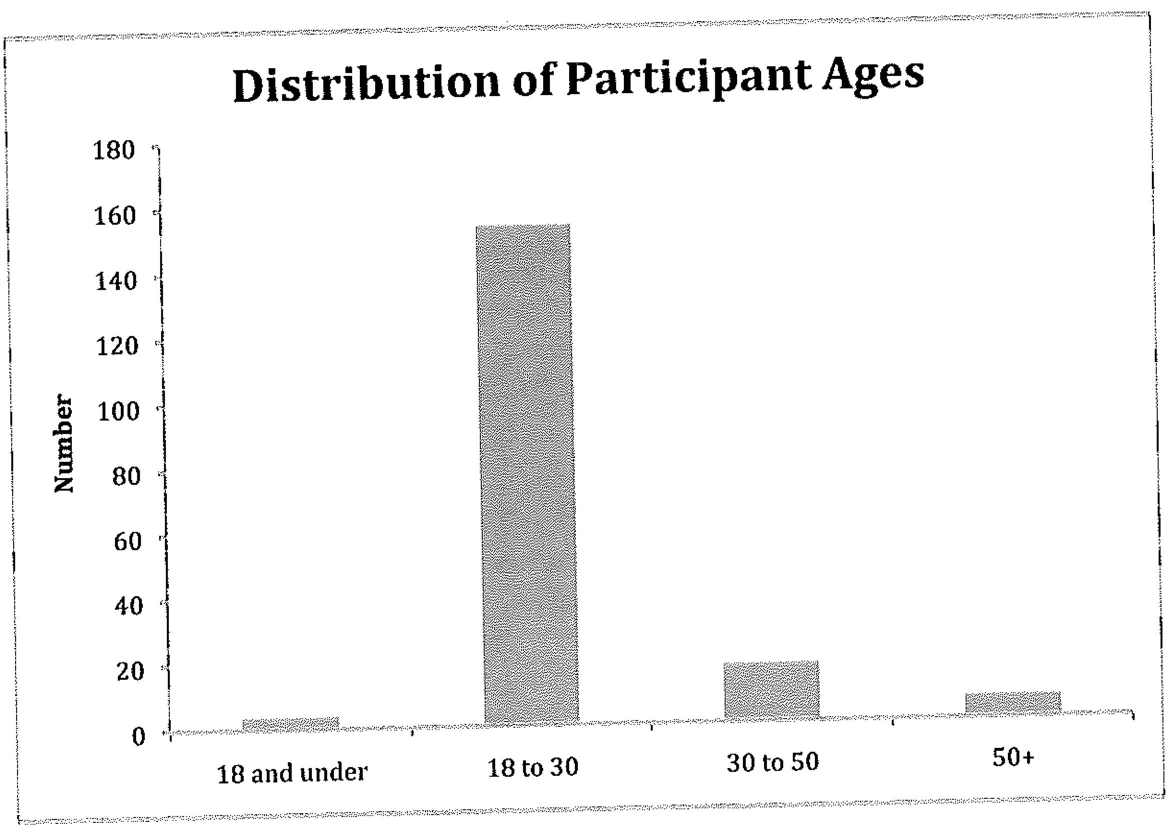
In the end, I was actually happy with how the majority of my questions turned out. In a future survey, I would make the short answer question a bit harder and require participants to discuss the composition of the Sun in more detail (gas vs. ionized plasma). The only other question that I would strongly consider changing is Question 5. This question was the most discriminating, but I am unsure how much of that is a real effect. So few people answered the question correctly that it is difficult to disentangle those who truly knew the answer from those who simply guessed and got lucky. This is not a topic that is thoroughly covered in most introductory astronomy classes and most people do not have any intuition for scales in our Solar System. However, despite my quavering over whether or not this question was a good one to include, it has led me to one clear conclusion—in any future introductory astronomy course that I teach, I will be sure to introduce my students to relative scales in astronomy.

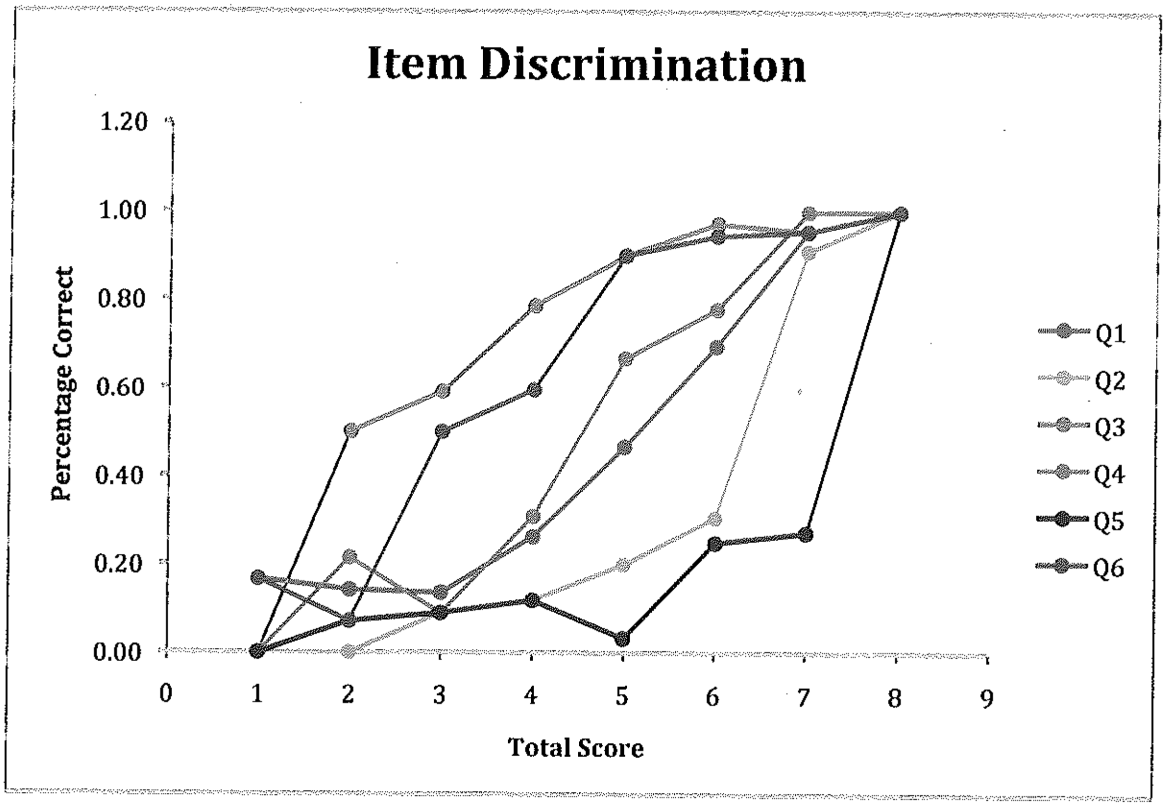
I do believe that using questions like these is an effective way to assess my subjects' understanding of key concepts in astronomy. It was fascinating to see certain misconceptions picked by the majority of people who answered a question incorrectly. Looking at the results of such a survey gives one a clear snapshot of the misconceptions held by a significant number of participants. As a result, using such tests would be a particularly effective tool while teaching a course. It would allow the professor to quickly see where student thinking might be flawed and then subsequently tailor lectures to address those misconceptions. Furthermore, designing questions with a range of 'turnover' points seems to be an effective way to create a Gaussian distribution of grades if that is the desired outcome. This is certainly a tool that I will try and incorporate in future course I might have the opportunity to teach.

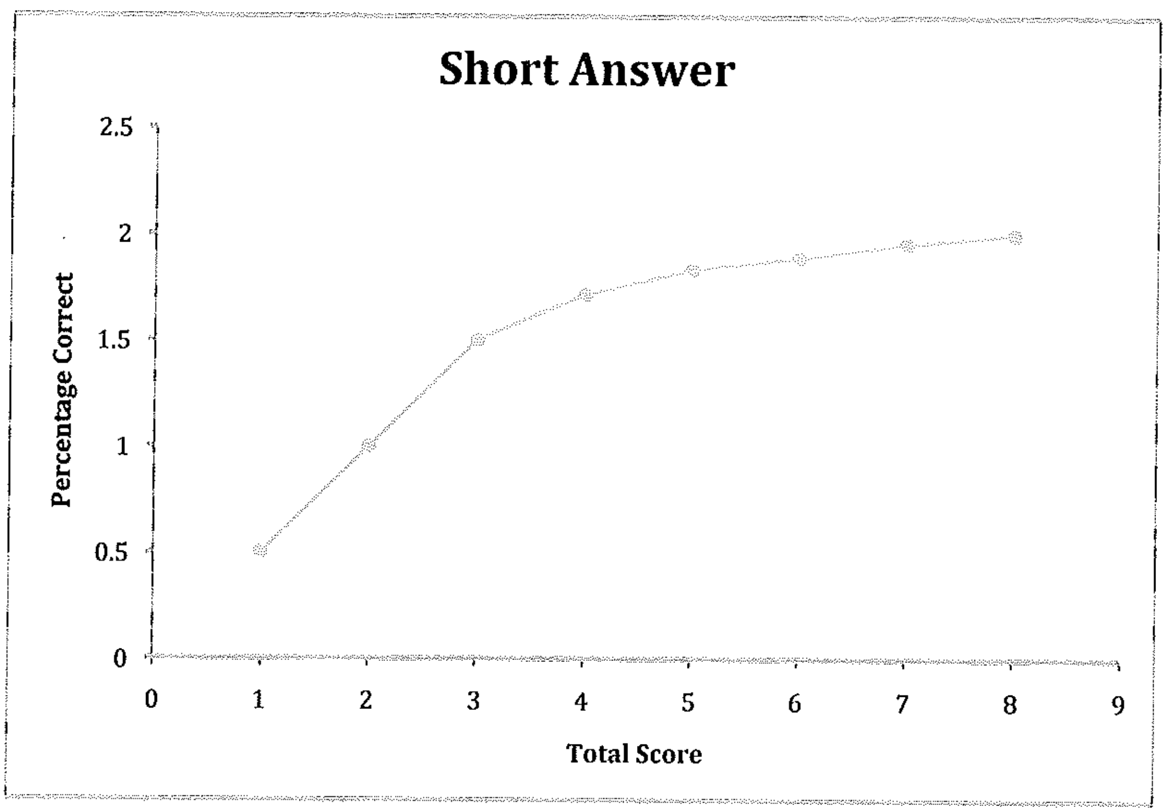
Sources

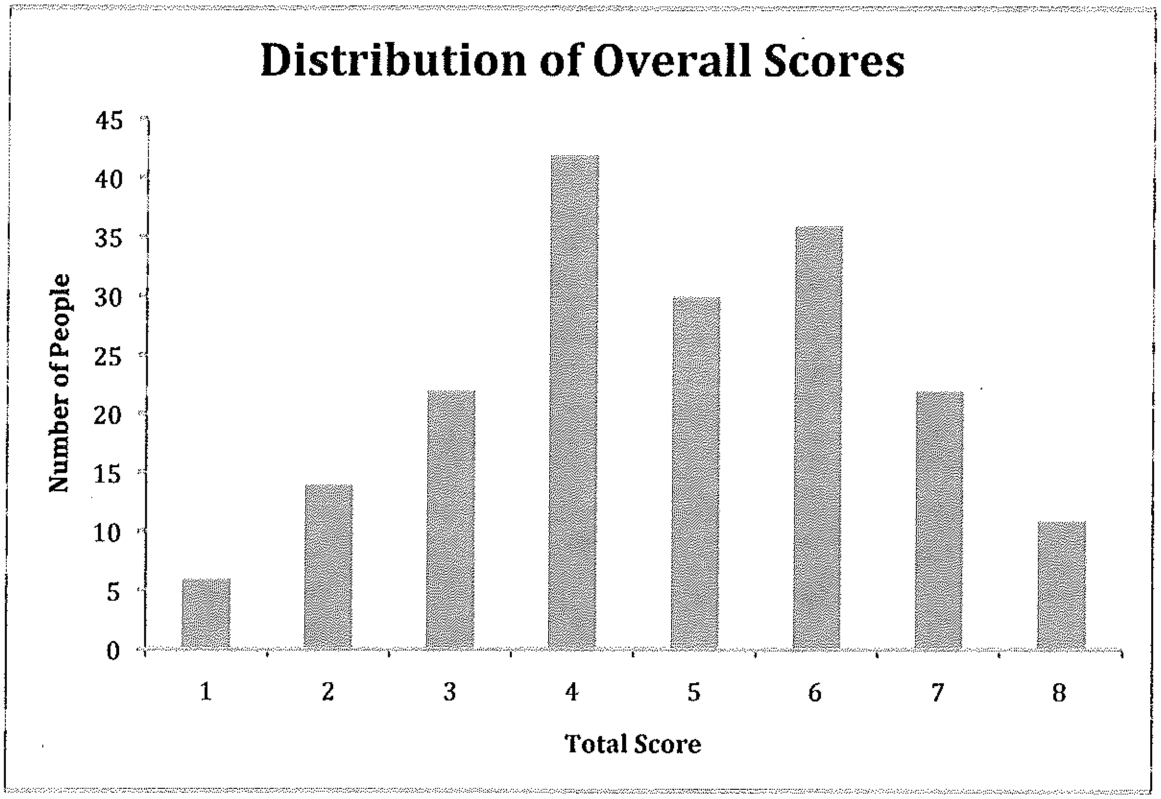
Sadler, Philip M. 1998. 'Psychometric Models of Student Conceptions in Science: Reconciling Qualitative Studies and Distractor-Driven Assessment Instruments. *Journal of Research in Science Teaching*, 35, 265-296.


Distribution of Participant Gender
120
100
80
60
40
20
0
Number
Male
Female
Other


Distribution of Participant Ages
180
160
140
120
100
80
60
40
20
0
Number
18 and under
18 to 30
30 to 50
50+


Item Discrimination
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Percentage Correct
0
1
2
3
4
5
6
7
8
9
Total Score
Q1
Q2
Q3
Q4
Q5
Q6


Short Answer
2.5
2
1.5
1
0.5
0
Percentage Correct
0
1
2
3
4
5
6
7
8
9
Total Score


Distribution of Overall Scores
Number of People
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
Total Score

Percent Correct							
Q1	Q2	Q3	Q4	Q5	Q6	Short Answer	Total Score
0.17	0.00	0.00	0.00	0.00	0.17	0.50	1
0.14	0.00	0.50	0.21	0.07	0.07	1.00	2
0.14	0.09	0.59	0.09	0.09	0.50	1.50	3
0.26	0.12	0.79	0.31	0.12	0.60	1.71	4
0.47	0.20	0.90	0.67	0.03	0.90	1.83	5
0.69	0.31	0.97	0.78	0.25	0.94	1.89	6
0.95	0.91	0.95	1.00	0.27	0.95	1.95	7
1.00	1.00	1.00	1.00	1.00	1.00	2.00	8

Score	Number?
1	6
2	14
3	22
4	42
5	30
6	36
7	22
8	11

Science Club for Girls

In the fall of my third year in college, I received an email from an organization called Science Club for Girls (SCFG) that was seeking undergraduate and graduate students who might be interested in teaching a science curriculum to elementary and middle school girls. I had always been interested in having an opportunity to teach, so I responded to the email immediately. SCFG runs science after-school programs for kindergarten through 7th grade girls at several schools in the Cambridge and Boston area and aims to provide mentorship for young girls who are interested in science. After several teacher and curriculum trainings, I was assigned to teach an Astronomy curriculum to 6th and 7th grade girls at the Amigos School in Cambridge, MA. Even though my major at Harvard was Astronomy, it still proved to be quite a challenge to come up with ways to make abstract astronomical concepts understandable and relevant to the students. I had to figure out how to teach science in a way that made my students care about it and want to learn more. However, I found that this was a very rewarding endeavor and I have continued to teach once a week every semester since then. In total, I have been involved with SCFG for eight semesters and taught curricula ranging from Architecture to Marine Biology to Engineering. Currently, I am teaching Archaeology to a group of 4th grade girls. I have enjoyed having the opportunity to show my students that science and math are important subjects that are worth caring about and studying. Developing an ability to teach and communicate science effectively is a demanding task that all scientists should undertake at some point in their careers.

During my senior year of college, I worked to start a chapter of SCFG at Harvard University. The goal of this chapter was to connect all of the Harvard students involved with SCFG and to help expand the reach of the program. This coming fall (2013), we will be opening a new SCFG site at the Amigos School in Cambridge, MA. The site will be entirely staffed and run by Harvard students, marking a significant stride for our college chapter.

You can find out more about Science Club for Girls here:

http://scienceclubforgirls.org

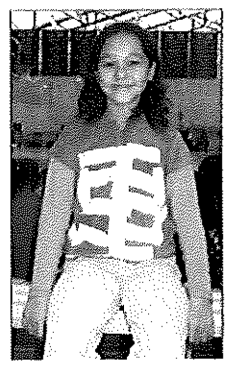
Program Highlights

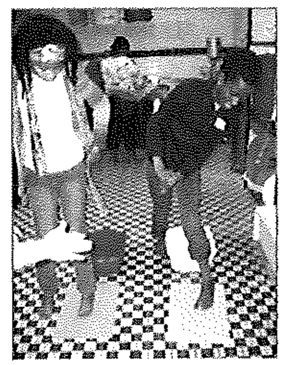
Mixing science and art, earth and space

Mentor-scientists Meredith MacGregor and Anna Strewler guided a group of 6th grade girls through Kids Capture the Universe, a curriculum developed by the Kavli Center for Astrophysics. Girls programmed a remote telescope to capture images of celestial bodies of their own choosing, manipulated the images to enhance color and effect, built artful representations of what they saw, and penned poems to accompany their science and art!

The Science of Sport

Wellesley College professor Connie Bauman and students in her sports medicine class treated our middle schoolers to a full day that included a foot print lab, analyzing a women's basketball game and their moves utilizing their new-found knowledge in sports and anatomy, and a dinner with their parents to learn about what foods best fuel the body for high energy activities. This event led to a wildly popular Saturday club on the science of sports at our Newton site in the spring.





From the 2009-10 Annual Report of Science Club for Girls

›ject on life and science
ve invited a group of twenty
ıreers to share their wisdom
's read these letters, relating
to their own experiences. They then wrote letters to their future selves that captured their aspirations and concerns. A group of the adult letter writers sat down with some of our JMs at a Meet the Bloggers event to answer teens' questions about their science and engineering careers and their lives.

Science Club for Girls

Building science literacy, sisterhood and self-confidenc

Co-Mentors who go 'Above & Beyond'... and Out To Space *December 7, 2009*

Posted by jburnstein in Clubs, Mentor volunteers.
Tags: Astronomy, Mentors, Nomination, Volunteers
trackback

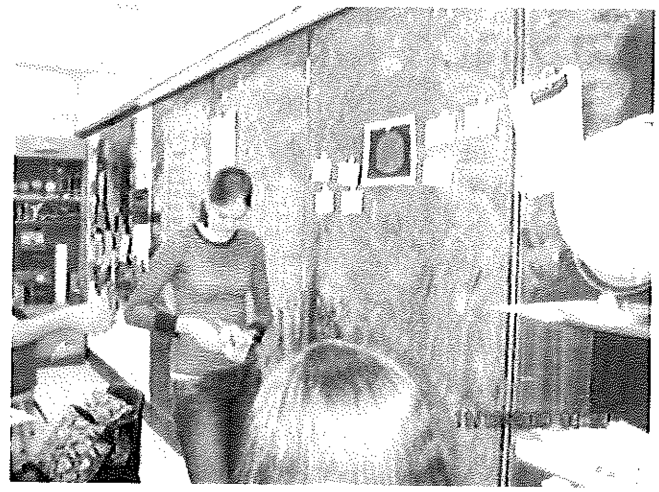
A short visit to Anna Strewler's and Meredith MacGregor's 7th grade Astronomy club was enough t understand why these women would have nominated each other as outstanding Mentors. The two work together well, and their girls stayed engaged and excited throughout the club session. Both are first time Mentors at the Amigos school — we hope they continue on with Science Club next semester! Thanks for your hard work.

Anna explains the activity

Anna Strewler's Nomination, ***by Meredith MacGregor***

I would like to nominate my co-mentor Anna Strewler a going above and beyond. We have been teaching the 6t and 7th grade girls the Kids Capture their Universe astronomy curriculum. Anna started off the program not having much of a background in astronomy, but sh has definitely made an effort to learn the material. At this point, she can answer most of the astronomy relate questions that the girls ask. A large part of the curriculum is processing astronomical images using a program called MicroObservatory. Anna has pretty much mastered this program and does a great job explaining it to the girls. Overall, Anna is a wonderful person to work with. She does a great job engaging the girls and teaching the material. And, she is always willing to do an extra task whether it be bringing in her own computer for the girls to work on or printing out processed images. Anna is definitely an awesome co-mentor.

Meredith MacGregor's nomination, ***by Anna Strewler***



Meredith sets up one-word 'Planet Poetry'

Using the phrase, "Above and Beyond" to describe Meredith MacGregor's approach to our Astronomy club is particularly apt. As someone who has a strong background in our curriculum material, her drive to share that knowledge with others has continuously impressed me throughout our sessions. She never passes up an opportunity to expand upon the existing material, isn't afraid to delve a little deeper into technicalities and mechanisms with the girls, and puts great value on sharing how each new activity, definition, or procedure relates to what professional astronomers and astronomy students like her accomplish on a day to day basis. Her willingness to share her personal experiences with and even questions about this material really has enhanced how the girls themselves connect with what they've been learning. This honest approach in her teaching style, I think, has been really instrumental in showing the girls that like Meredith, they, too have the right to question what we're looking at. The level of comfort with personal inquiry on the part of every single girl in our club has grown immensely over the past several weeks, and I think this is owed to Meredith's public display of her own learning experiences. Furthermore, this honest display has really gained for Meredith the girls' respect in getting across material that can seem daunting. Throughout the past several weeks, I've watched as she's grown more and more comfortable with sharing her own connection with astronomy, while simultaneously the girls have grown more and more confident in what we're learning and expressing their own questions about it. She acts as a fun and solid example for each girl and for myself of a woman who enjoys, takes seriously, questions, and is at moments in awe of what she studies and this has had a major effect on the level of intellectual and personal comfort and growth I've witnessed our club members take on.

Comments»

1. **girlstartblog - December 8, 2009**

   Congratulations Anna and Meredith! You are both "star mentors"! Thank you for everything you do every week to inspire girls in science! That is what we aim to do every day at Girlstart (www.girlstart.org). We are giving you virtual "high fives"!!

   ~Julie Shannan
   Deputy Director

Girlstart

Reply

Connie - December 8, 2009

Julie,

We love your program at GirlStart!

–Connie

Reply

2. **Connie - December 8, 2009**

   Anna and Meredith,

   Thank you for really sharing of yourselves. That is truly the greatest gift for the girls. I love that you have nominated each other–clearly you are learning from each other and have great respect for each others' contribution.

   Knowing that we have such reflective mentors like you working with our girls certainly makes m smile!

   Thanks again!

   Sincerely,
   Connie
   Executive Director
   SCFG

   Reply

3. **Kareen Wilkindon - December 9, 2009**

   You ladies run an awesome club! I'm honored to be able to see it so often.

   Reply

4. **2010 Year-in-Review « Science Club for Girls - December 20, 2010**

   [...] Toy Design, created by MIT mentor Emily Conn; Archaeology, created by Harvard grad student and mentor Bridget Alex; and Sports Nutrition, created and taught by Wellesley profess Connie Bauman and her [...]

   Reply

Theme: Regulus by Binary Moon.
Blog at WordPress.com.

Science-Focused Clubs Empower Young Women

By JULIE R. BARZILAY, CRIMSON STAFF WRITER
September 30, 2011

2 COMMENTS EMAIL PRINT Like 65

MOST READ

1. Fifteen Hottest Freshmen '16: Around Our Town
2. Joanna Li '12 Dies
3. An Open Letter to the Harvard Community
4. Students Shed Clothing, Reading Period
5. Harvard Honors 81 With Hoopes Prize

GIF89a

Eva Gillis-Buck '12, a joint concentrator in Women, Gender, and Sexuality and Human Developmental and Regenerative Biology, has spent a great deal of her undergraduate career unpacking the gender paradigms that pervade autism and neuroscience research.

But whenever her studies of gender biases start to seem discouraging, Gillis-Buck says she looks to the inspiring women that work alongside her in her stem cell lab.

"They do not fulfill the stereotype of the geeky scientist alone in the corner," she says. "They're super smart but also very well-rounded, very fun, very silly."

Understanding the importance of these types of role models inspired Gillis-Buck and Meredith A. MacGregor '11 to launch the Harvard Science Club for Girls this past spring. The program sends Harvard women and other female scientists into schools each week to mentor young girls and foster enthusiasm about science.

"We're not just there to convey information, but to show them that science can be fun," Gillis-Buck says. "That you can be a scientist and have lots of interests and not look like Einstein."

Harvard Science Club for Girls joins a growing contingent of campus organizations that support women in science, technology, engineering, and math (STEM).

Among these groups are a new women's science magazine called Women Innovating Science and Engineering (WISE) Words, WISHR (Women in Science at Harvard-Radcliffe) and WISTEM (a mentoring program for females in STEM fields run by the Women's Center).

"The number of women who graduate with STEM degrees and continue on to the next phase shrinks at every step," notes Women's Center Director Gina Helfrich. "I largely understand groups for women in science to be a place that creates a sense of community and belonging for its members. Through that network of support, they help to keep women in the STEM pipeline."

THE 'WHOLE GIRL'

As Gillis-Buck explores the "pervasive and problematic theory" of "autism as the extreme male brain" for her thesis, she says she is excited about unpacking the consequences of doing neurobiological research under a gendered paradigm.

Her thesis touches on the distinction between what her advisor, History of Science and WGS Assistant Professor Sarah S. Richardson, calls the topic of "gender and science" and the topic of "women in science."

The former, Richardson explains, deals with the way gender conceptions influence the content and practice of science. Meanwhile, issues of "women in science" deal with attracting women to STEM fields and with women's status in these professions.

Richardson—who also serves as the faculty advisor for the Harvard Science Club for Girls—says she sees these issues as intrinsically linked.

"If a field of scientific research is systematically in its knowledge excluding women, as medicine once did, if it is perpetuating theories that are sexist or misogynist or in some way sex-biased, I would suggest that this may contribute to the hostility of that field towards women entering it," she says.

Breaking stereotypes is one of the Harvard Science Club for Girls' main missions. From anatomy to crystals to circuits, the Club's lessons are meant to be diverse and engaging—but Gillis-Buck says the program is mainly about fostering "the whole girl" and demonstrating that "science is for everyone."

The Club also provides a positive community for its older members, according to Gillis-Buck and Richardson.

"[Engaging with the young girls] puts them at the front lines of that work and will make them, as they move up the ranks, very sensitive ... leaders in the effort to draw women and girls into science," Richardson says.

THE MERITS OF MENTORS

When WISHR Co-President Jennifer K. Cloutier '13 returned home this past summer, she says she was shocked to find her favorite physics teacher instructing an all-male class.

"He asked me to come back sometime this year and talk about science, tell the girls not to be scared of it," she says, noting that the episode re-energized her WISHR plans for the year.

One aim of both WISHR and WISE Words Magazine, founded this spring by Julia C. Tartaglia '11 and her sister Christina E. Tartaglia '09, is to increase the visibility of women already in science.

"Most people can't name one female scientist, and we really want to change that," Christina Tartaglia says.

Women's Leadership Conference organizer Rachel M. Neiger '12 also emphasized the struggle to attain and navigate female science networks.

"It's sometimes hard for women to advance in science because there isn't that network of female advisors, so it's harder to get appointments and grants," she says.

Leslie A. Rea '12, who organized the first "Women in Science" panel in the WLC's 24-year history, helped recruit School of Engineering and Applied Sciences Dean Cherry A. Murray to speak about how she became a leader in science and about the importance of mentoring.

Rea says her personal mentor has been Sujata K. Bhatia, who joined SEAS in May as the assistant director of undergraduate studies for Biomedical Engineering.

Bhatia says that many of the students she encounters worry about work-life balance and whether or not they have what it takes to succeed in engineering. Bhatia encourages women to speak up in class, so they can "learn that they have a unique voice to contribute to the field."

WISHR Co-President Swara S. Kopparty '12, an Applied Math concentrator notes that in the future she hopes WISHR's bi-annual National Symposium for the Advancement of Women in Science will include speakers in fields like economics and computer science as well as hard sciences.

WIDENING THEIR IMPACT

When WISE Words won the i3 Competition in the spring of 2011, the organization received funding its founders hope will allow the publication to have a national impact.

"We think that our online presence allows us to have really wide-spread effects, so our audience can be nation-wide," Julia says. "People might not have time to go to an event or a conference ... but everybody has time to check their computer."

Professor Melissa Franklin, who was named the first female chair of the Harvard Physics Department in 2010, says that though the department's female population has risen in recent years, there are still inherent obstacles in the system.

"It's hard to be a minority," Franklin says. "I used to think it had a lot to do with confidence. If girls had confidence, they would just learn physics, no matter what anybody else thought."

Susanne F. Yelin, a senior research fellow in the physics department, said she feels that "on average, women doubt themselves much more than men," and that "one always feels like the odd one out at meetings where everyone else is male."

For these reasons, she believes a publication like WISE Words that promotes the visibility of women in science is invaluable.

Whether facilitating mentorship relationships, challenging stereotypes, or providing role models, these clubs have in common a desire to make evident the potential for rewarding and engaging scientific careers for women.

Richardson notes that once women break into certain fields, they ask different types of questions, thereby generating new knowledge and transforming the discipline in exciting ways.

"If a woman is willing to stick with a career in science or engineering, she has a really bright future," Bhatia says.

"With the girls in my class, I tell them: 'you belong here.'"

—Zhanrui Kuang contributed reporting to this story.

—Staff writer Julie R. Barzilay can be reached at jbarzilay13@college.harvard.edu.

Landmarks of the ISM

An educational website I designed as part of a graduate course

* -> light blue text = hyperlinks

About this Page

A Bit About the Structure of the Website . . .

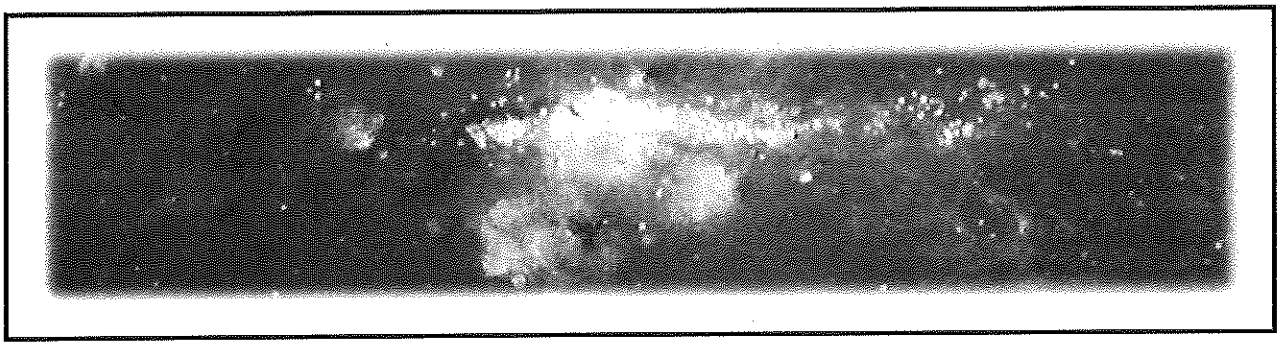
This page was designed in Spring 2013 as part of a final project completed for a class on the interstellar medium (ISM) at Harvard University taught by Alyssa Goodman. Most introductory astronomy courses never cover the ISM, skipping over it in favor of stellar and planetary evolution or galaxies and cosmology. However, understanding the ISM is vital to truly understand how stars and planets form and how galaxies evolve. Thus, the goal of this project is to provide an introduction to how beautiful and fascinating the ISM can be. For the full experience please refer to the WorldWideTelescope tour I created as well. Pages on this website provide more information about the images displayed and the topics discussed in the tour. Refer here to answer any of your ISM physics and astronomy questions!

A Bit About the Level of the Website ...

Don't be scared away if you are not familiar with astronomy! The narration for the WorldWide Telescope tour is written at a level accessible to the public. You should be able to understand everything included in the tour without having any previous knowledge of the subject. If you are a more advanced student of astronomy, this website is meant to fill in all of the additional details and physical explanations you might be curious about. Whenever a more complicated topic is mentioned or hinted at in the tour, hyperlinks will direct you to a specific page on this website. Those pages explain the nuances of that topic at a higher level than is included in the tour. The goal of splitting the information up in this way is to allow people to interact with this project and explore the ISM at whatever level they feel most comfortable with.

An additional note: If you watch the tour and have further questions, don't hesitate to comment and ask for

an explanation. I'll try and follow-up as quickly as possible! This website is not a fixed entity. It can evolve to reflect what viewers are most interested in learning more about!



A Bit About the Author . . .

I am currently a second-year graduate student at Harvard University. My primary research interests are the evolution of circumstellar disks and the formation of planetary systems. Much of my research makes use of instruments like the Submillimeter Array (SMA), the Atacama Large Millimeter/submillimeter Array (ALMA), and the Jansky Very Large Array (JVLA). As a result, I am also interested in looking more into dust and grain dynamics and the techniques of radio interferometry. If you want to know a bit more about me, check out my webpage:

https://www.cfa.harvard.edu/~mmacgreg/index.html

Landmarks of the ISM

WorldWide Telescope Tour that accompanies the website

* -> light blue text = hyperlinks

The Tour

So, how do you watch the tour that goes along with this website? Look no further!

The complete WorldWide Telescope file can be downloaded here:

Landmarks of the ISM

This tour is viewed best using the WorldWide Telescope Windows Client. You can download the client here. Unfortunately, there is no WorldWide Telescope client for Mac or Linux machines. A suitable alternative is to load the tour into the WorldWide Telescope Web Client, which you can find here. In order to play the tour in the web client follow these simple steps:

1. Download the tour (above) and save it on your computer
2. Open the WordWide Telescope Web Client and click on the 'Explore' tab
3. Click 'Open' and then 'Tour' and select the downloaded file
4. Learn about the ISM!

Depending on your web connection, some of the features of the tour might not load correctly. However, the complete tour narration and most of the images included are available on this website, so you can still have the complete experience slow internet connection or not.

Another option is to view the tour directly in your web browser at this url:

https://www.cfa.harvard.edu/~mmacgreg/WWT/WWT_new.html

A few caveats about this option… This html version of the tour attempts to render a WorldWide Telescope environment in your web browser. As a result, some of the tour features might not load correctly. Furthermore, the audio for the tour tends to load more slowly than the images. In order to allow time for the audio and images to sync up, it is best to click 'Stop/Pause' and allow the tour to load before clicking 'Play.' Finally, the hyperlinks do not work in this html version of the tour, so be sure to refer to this webpage whenever a piece of blue text pops up that you want to learn more about.

Finally, the complete transcript of the tour is also available for those who want to read along or are having difficulties with the sound rendering in any of the above methods for watching the tour:

Tour Narration

Thanks for your interest in watching this tour!

Landmarks of the ISM

List of topics included in the website

* -> light blue text = hyperlinks

The Main Page

This page is here to orient you to all of the information contained on this website. If you want to learn more about the structure of this website as a whole, check out this page. All of the topics that appear as hyperlinks in the related WorldWide Telescope Tour are listed below. There are even a few bonus topics and links thrown in for good measure. All of the topics are divided into three general categories to help guide you towards what you are most interested in learning about. Just click on a topic to go to the page that discusses it. Have fun exploring!

Astronomical Observing (Techniques, etc.)

These pages discuss different wavelengths of light, specific telescopes, and astronomical techniques. Check these pages out if you are curious about where exactly the images in the tour came from.

- Digitized Sky Survey (DSS)
- Distances in Astronomy (A Cheat Sheet)
- H-alpha Emission
- Infrared (IR) Astronomy
- NASA's Great Observatories
- X-ray Astronomy

Physics of the ISM

These pages discuss more advanced concepts mentioned briefly in the tour. By reading these pages, you should come away with a more complete understanding of the complicated physics that produces the spectacular images you can see in the tour.

- Dust in Space
- Emission Nebula
- Forbidden Line
- Polycyclic Aromatic Hydrocarbons (PAHs)
- Protostars
- Radiation Pressure
- Supernovae and Shocks
- Stellar Winds
- Triggered Star Formation
- Ultraviolet Radiation and Young Stars

Specific Astronomical Objects

These pages discuss each of the regions shown in the tour in greater depth. Refer to these pages if you want to learn a bit more about each of these regions, particularly the physical explanation of the images shown in the tour.

- HD 206267
- IC 1396
- Kepler's Supernova Remnant
- NGC 2264

Landmarks of the ISM

[illegible]

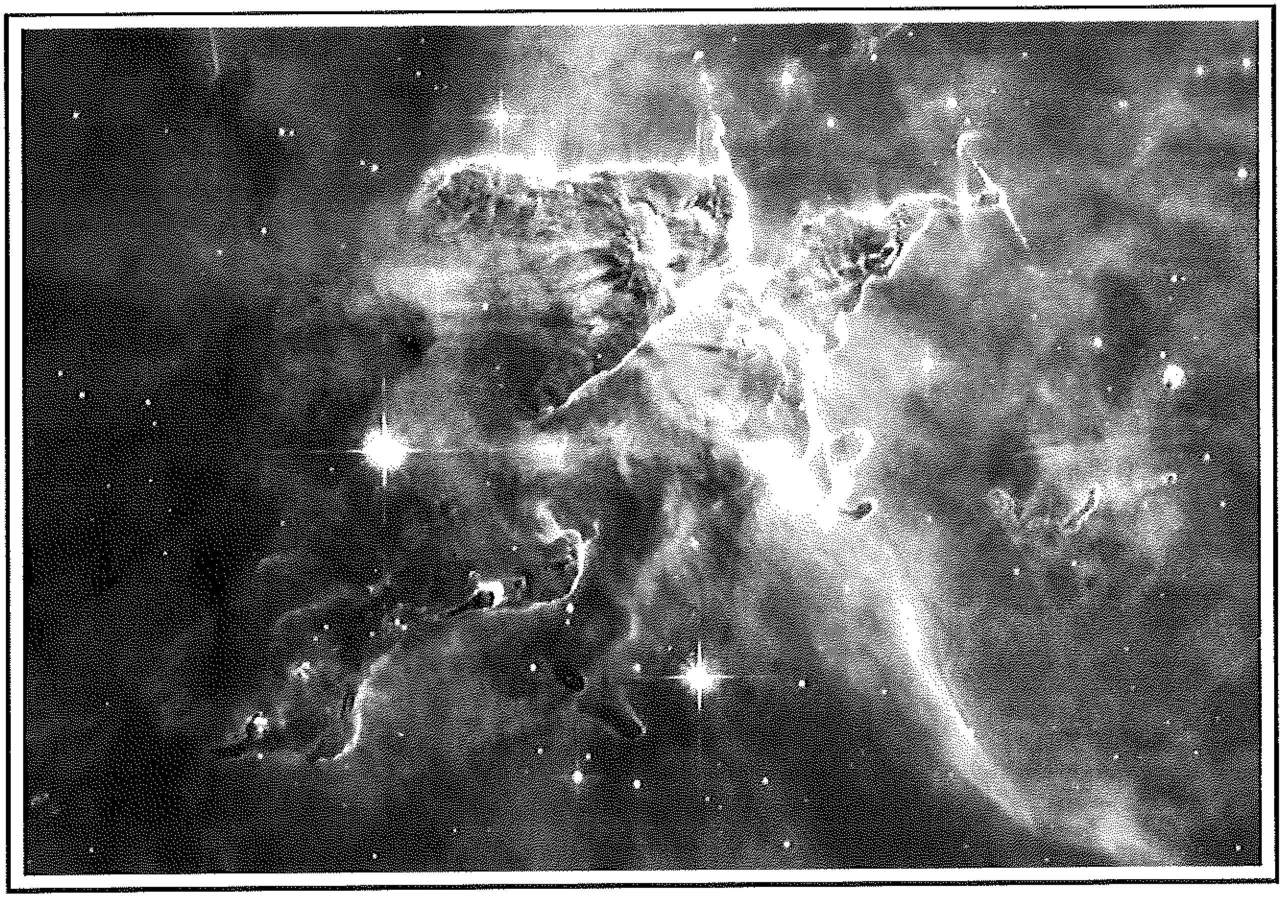
Sample website page

* -> light blue text = hyperlinks

An Overview of the ISM

What exactly is the interstellar medium (ISM)? In his 2011 textbook, Bruce Draine writes 'The interstellar medium, or ISM, is, arguably . . . the most important component of galaxies, for it is the ISM that is responsible for forming the stars that are the dominant sources of energy.' Essentially, when we talk about the ISM, we are talking about *everything* in our galaxy that is between the stars. Draine divides all of this 'stuff' into seven components:

1. **Interstellar gas**: Anything (ions, atoms, or molecules) that exists in the gas phase and has a nearly thermal velocity distribution. This is primarily in the form of hydrogen or helium along with some additional heavy elements
2. **Interstellar dust**: Dust in space! Or, in more technical terms, small solid particles mixed in with the interstellar gas
3. **Cosmic rays**: Ions and electrons that are moving relativistically (not thermal!)
4. **Electromagnetic radiation**: Photons from any source that might produce radiation (the cosmic microwave background, stars, thermal emission from dust, etc.)
5. **Interstellar magnetic field**: Magnetic field produced by electric currents in the ISM
6. **Gravitational field**: Fairly self-explanatory- force due to all of the matter in the galaxy (ISM, stars, dark matter, etc.)
7. **Dark matter particles**: Particles that only exhibit weak interactions, but account for the majority of mass in the galaxy



To learn even more about the ISM and what different wavelength observations tell us about its many component, refer to this Prezi presentation:

The Illustrated ISM

Or, look at the related tour and WordPress site written by Kate Alexander:

The Multiphase ISM

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Be the first to like this.

Landmarks of the ISM

Sample website page

★ -> light blue text = hyperlinks

Distances in Astronomy

Astronomers are constantly dealing with distance scales that are unfathomable to the average person. As a result, there are many distance measures that only astronomers are familiar with. For example, what exactly is a parsec? It's a pretty big distance, but how big exactly? Here's a quick overview of astronomical distances to help give a better sense of scale elsewhere in the website.

Within the Solar System, astronomers typically use a unit called the '**Astronomical Unit**' (AU) defined by the average distance between the Earth and the Sun.

- 1 AU = the average distance between the Earth and the Sun
- 2.5 AU = the distance from the Earth to Mars
- 31.9 AU = the distance from the Earth to Pluto

Outside of the Solar System, the most common unit used is the '**parsec**' (pc).

- 1 pc = 3.26 light years
- 1.3 pc = the distance to the nearest star to Earth (Proxima Centauri)
- 1 pc = 206265 AU (by definition)

Within our galaxy, astronomers typically refer to '**kiloparsecs**' (kpc).

- 1 kpc = 1,000 pc
- 7.6 kpc = the distance from the Earth to Sagittarius A* (the supermassive black hole at the center of the Milky

Way galaxy)

When considering the distances between galaxies or cosmological distances, astronomers switch to '**Megaparsecs**' (Mpc).

- 1 Mpc = 1,000,000 pc
- 0.78 Mpc = the distance from the Earth to the Andromeda galaxy (the nearest galaxy to the Earth)

Finally, when referring to the radius or mass of objects, astronomers like to relate things to the Sun.

- 1 solar mass = the mass of the Sun = 1.99 x 10^33 grams
- 1 solar radius = the radius of the Sun = 6.96 x 10^10 cm
- The total mass of the Milky Way galaxy = 3 x 10^12 solar masses (meaning the entire galaxy weighs 3,000,000,000,000 times more than the Sun!)

And, if all of those numbers still seem a bit overwhelming, just refer to this rather fantastic view of relative distance/size scales in astronomy:

http://xkcd.com/482/

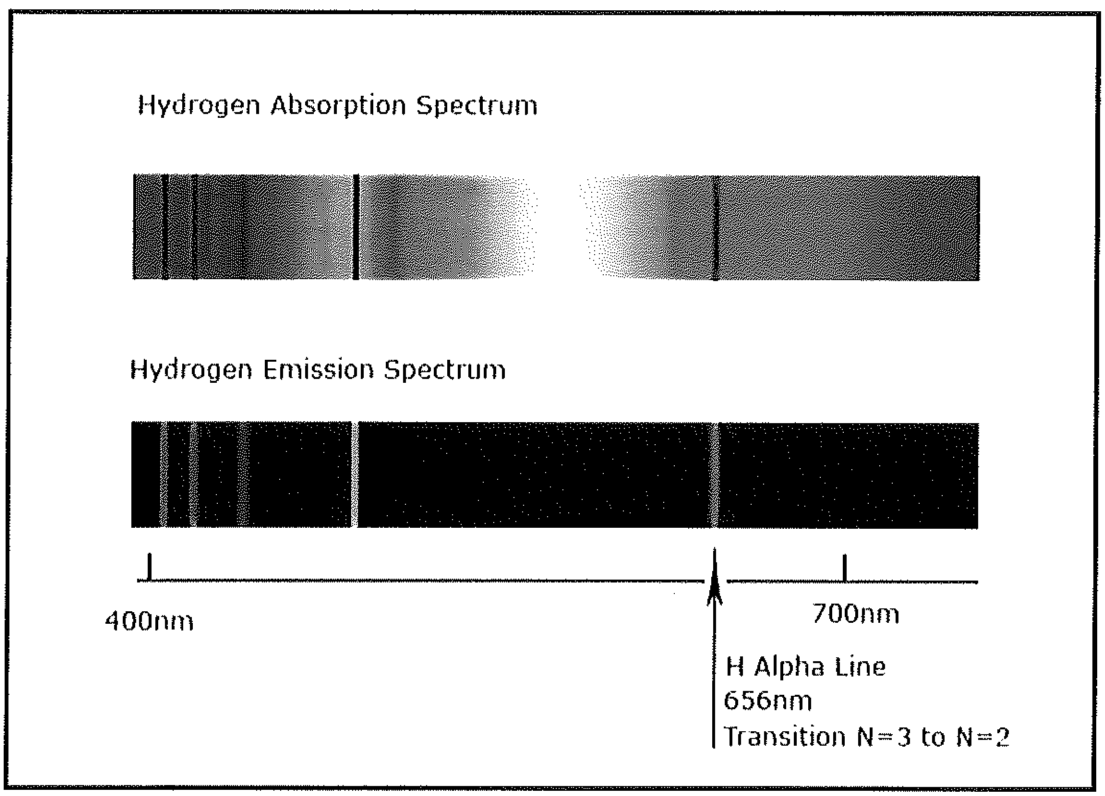
Landmarks of the ISM

Sample website page

* -> light blue text
= hyperlinks

H-alpha Emission

H-alpha (Hα) emission is the red visible spectral line created by a hydrogen atom when an electron falls from the third lowest to second lowest energy level. This transition corresponds to a wavelength of 656.28 nm (red light) and is the first transition in the Balmer series. The spectrum below shows the four visible hydrogen emission spectrum lines that make up the Balmer series, with the H-alpha transition in red on the far right.



The Balmer Series

The Bohr model of the atom describes electrons as existing in quantized energy levels surrounding the atom's nucleus. Electrons can jump from the ground state (n = 1) to higher energy levels if the atom is excited (absorbs incoming radiation). When an excited electron drops back to a lower energy level, it emits light at a specific wavelength corresponding to that particular transition. The set of transitions from a $n \geq 3$ energy levels to the n = 2 energy level is named the 'Balmer Series.'

Astronomical Implications

It takes almost as much energy to ionize a hydrogen atom as it does to excite the atom's electron to the n = 3 energy state. In fact, it is very rare for an electron to be excited to this energy state without being removed from the atom. Once an atom is ionized, the nucleus and removed electron can recombine to form a new atom with the electron typically in a higher energy state. This electron will then cascade back to the ground state, a process which produces H-alpha emission about half of the time. Thus, observing H-alpha emission in a region indicates that hydrogen is being ionized there. Astronomers use observations at this wavelength as an effective probe of star formation regions, where surrounding gas is begin continually ionized by newly formed stars.