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**Comparing Modern Methods
of Active & Collaborative Learning
& Learner-Centered Teaching
to Traditional Lectures**

Michael C. LoPresto

*A thesis submitted for the degree
Doctor of Philosophy
at the
Centre for Astronomy
James Cook University*

2012

Statements & Acknowledgements

Statement of Access

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Statement of Sources

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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Date

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Statement of Previous Publication & Presentation

This thesis describes work carried out for the Centre for Astronomy at James Cook University, Townsville, Australia. As an Internet-based international student, I have never been on the Townsville campus but have done all of my work at Henry Ford Community College (HFCC) in Dearborn, Michigan where I am a full-time instructor of Physics & Astronomy. All work was undertaken while I was enrolled at James Cook University under the direction of my advisor Dr. Carlton R. Pennypacker.

All work presented in this thesis is my own. Slightly modified versions, research done specifically for this thesis, have appeared as the following published papers, all of which I am the first author, and were given in the following presentations;

Chapter 4: “An Astronomical Misconceptions Survey” with Steven R. Murrell, *Journal of College Science Teaching*; Volume 40, Number 5 (2011); presented at American Association of Physics Teachers Michigan Section Meeting, Hope College, Spring 2010; Contributed Poster, Astronomical Society of the Pacific, Cosmos 2010, Boulder Colorado, Summer 2010.

Chapter 7: “Using the Star Properties Concept Inventory to Compare Instruction with Lecture-Tutorials to Traditional Lectures” with Steven R. Murrell, *Astronomy Education Review*; Volume 8 Issue 1 (2009); presented at American Association of Physics Teachers Michigan Section Meeting, Michigan State University, Spring 2009.

Chapter 8 “Assessment of a Solar-System Walk “ with Steven R. Murrell and Brian Kirchner, *The Physics Teacher*, April 2010; presented at American Association of Physics Teachers Michigan Section Meeting, Michigan State University, Spring 2009.

Chapter 9: ”A Comparative Planetology Activity” *The Physics Teacher*, May 2010, with Steven R. Murrell; presented at American Association of Physics Teachers, National Meeting Chicago, Illinois, Winter 2009, Michigan Section Meeting, Michigan State University, Spring 2009

Chapters 10 & 11: “Using Visual Assessments and Tutorials to teach Solar System Concepts in Introductory Astronomy” *Astronomy Education Review*, (9) 1 (2010); Contributed Poster, American Association of Physics Teachers, National Meeting, Ann Arbor Michigan, Summer 2009; presented at Hands on Universe Conference, Yerkes Observatory, Summer 2009

Chapters 12 & 13: “Comparing a Lecture to a Tutorial”, *Physics Education*, February 2010; Contributed Poster, American Association of Physics Teachers, National Meeting, Ann Arbor Michigan, Summer 2009; presentation at Hands on Universe Conference, Yerkes Observatory, Summer 2009

Michael C. LoPresto
Saline, Michigan

Acknowledgements

Sometime during 2007 I was making my monthly perusal of Astronomy Magazine and I noticed the advertisement for James Cook University's online programs in astronomy. I had seen them many times before, except this was the first time that I had noticed that it included "*Doctoral Degrees.*"

Ever since I had turned 40 years of age in 2005 I had been considering that after 15+ years of teaching physics and astronomy that it was time to undertake a doctorate. My main hurdle was that even if I did not have a family to provide for, I was not interested in leaving my job for an extended period of time.

After investigating the link *Doctorate Program* on the James Cook University Centre for Astronomy website, I emailed Program Director, Dr. Andrew Walsh and asked, since teaching introductory astronomy was a large part of what I do in my position at Henry Ford Community College (HFCC), if it would be possible to do a doctoral thesis focusing on astronomy education. He very quickly responded by putting me in touch with Dr. Carl Pennypacker of the Space Sciences Lab at the University of California-Berkley as a potential advisor.

After exchanging a number of emails, Carl and I decided on a proposal for a project and very soon I was applying for admission to the program for the fall of 2008. I thank Dr. Andrew Walsh for being initially receptive to my program focusing on astronomy education and his guidance as director throughout the program. I also, of course, thank my advisor, Dr. Carl Pennypacker, for all his encouragement of and enthusiasm for my project. I also thank him for the invitation to the Hands On Universe (HOU) conference that he organizes at Yerkes Observatory to present my early work and meet him in person. Thanks also go to recent JCU Doctor of Astronomy graduate, Dr. Patrick Miller of Hardin-Simmons University, whom I met at HOU, for his encouragement and the use of his thesis as an example of proper formatting.

I thank my colleague, fellow instructor of Physics & Astronomy at HFCC and friend, Steven R. Murrell for his participation in the project. Without his willingness to teach his students with the instructional materials I was developing and implement the numerous assessments, this project would not have been possible. His input through many informal discussions about the project and the material was also extremely valuable. This has also been true of HFCC-adjunct astronomy instructor James Marks, I thank him and also Eric Rasmussen, Carrie Zaitz and Roxanne Crabill for similar participation and of course the literally hundreds of HFCC introductory astronomy students that participated in different parts of the project throughout its duration.

Also at HFCC, I thank the members of the 2009 Sabbatical Committee who saw fit to grant my request for my first ever sabbatical-leave from HFCC at the end of my 20th year of teaching there to begin writing this dissertation. I also thank HFCC President, Dr. Gail Mee for approving my sabbatical and I thank the architects of our AFT-LOCAL 1650 contract and those who approved it for financial support of this project.

I spent my Winter 2010 sabbatical writing the initial drafts of my thesis as a Visiting Researcher in the Astronomy Department at the University of Michigan in Ann Arbor. I thank the chairman, faculty and staff of the department for making me feel welcome during my stay in what I have always felt to be an academically inspiring environment and especially Professors Fred Adams and Don Bord for sponsoring the request for my visit.

Special thanks to Don Bord, Professor at both the Ann Arbor and Dearborn Campuses of the University of Michigan, for recommending me to the JCU Doctoral Program, letting me use his Ann Arbor office during my sabbatical and including me in the NSF-Funded Telescope Project at UM-Dearborn. The experience I gained from that project was “instrumental” in my being granted advanced standing for *AS5012-Astronomical Instrumentation* at JCU.

I also received advanced standing in AS5011-*Modern Astrophysics* at JCU, in no small part due to the astrophysics courses I took from Dr. Charles Cowley as part of the MS degree I earned from the University of Michigan in 1989, thanks Chuck! I also thank Dr. Alexandra Oakes of Eastern Michigan University (EMU) in Ypsilanti, MI, for the Research Master's Thesis I did with her at EMU in 1996 that also helped fill the requirements for admission to JCU's doctoral program.

Astronomy Education Research colleagues I need to thank are Dr. Tim Slater, *Excellence in Higher Education Endowed Chair in Science Education* at the University of Wyoming for recommending me to the JCU Doctoral Program and initially getting me interested in active and collaborative learning and learner-centered teaching.

Tim also did a detailed review of this work after its initial submission. His suggestions prompted me to rethink both individual parts of my thesis and the big picture, both of which made it a better work. I thank him and Dr. Nick Lomb for being willing to take on this arduous task for me.

I also thank Gina Brissenden and Dr. Ed Prather of the NASA/JPL Center for Astronomy Education (CAE) at the University of Arizona since 2007 for also being instrumental in my initial interest in active and collaborative learning and learner-centered teaching and for including me in a *Collaboration of Astronomy Teaching Scholars* (CATS) and this project as part of the CATS project, *Solar System Concept Inventory (SSCI) & Solar System Lecture-Tutorials Project* which included financial support for the project.

Thanks for financial support also goes Pearson Higher Education, publishers of the *Astronomy Media Workbook* (LoPresto, 2011) and Kendall-Hunt Publishing Company, publisher of *Fundamental of College Astronomy* (LoPresto, 2011, 2012), where several of the activities developed for this work have been published.

Last and certainly not least, I thank members of my family. My mother, Mel LoPresto for loaning me the “start-up” funds for the program, my father Dr. James C. LoPresto, for funds that helped me finish. I also thank my maternal grandmother, Dr. Nellie Juskenas, at the age of 93 years at the time of this writing and to whom this work is dedicated for all the support she has given my family and I over the years.

Finally and mostly, I thank my lovely wife of 23 years, Jan, and my children, Sarah, Emily and Sam for always keeping me grounded in what is really important in life.

Preface

This work originated in the summer of 2000 after the *Cosmos in the Classroom Symposium*, sponsored by the *Astronomical Society of the Pacific* in Pasadena, California. There, through a series of workshops, I was introduced to “Active and Collaborative” learning and was engaged in discussions with some of the pioneers of its use in introductory astronomy, among them, Tim Slater, Gina Brissenden, Andrew Fraknoi, Doug Duncan, Beth Hufnagel and others.

By that time, I had already been teaching introductory astronomy at Henry Ford Community College (HFCC) in Dearborn, Michigan for 10 years. The endeavor was becoming increasingly unrewarding as it became clear to me, mostly through the lack of student participation and test results that the traditional course, that amounted to a slide/transparency show with accompanying lectures was, in some fundamental way, not working. I wanted to move college astronomy beyond this with the hope that students might actually learn something conceptually significant, with real science behind it.

Upon my return to teaching in the fall of 2000, I began trying activities, some that had been shared with me by my new colleagues from *Cosmos in the Classroom*, others I developed myself, in my classes. I also had the good fortune in the spring of 2001 to be invited through a grant to team-teach an introductory Earth Science course that was part of a new science-education curriculum at HFCC’s neighbor, the University of Michigan-Dearborn, that was based on active and collaborative learning techniques.

Soon, I was “hooked.” I had “bought-in” to these techniques, began attending more workshops and building a repertoire of inquiry-based collaborative activities, developed by others and myself. I considered myself a “disciple” of the *Cognition in Astronomy & Physics Education Research* (CAPER) team (see CAPER, <http://www.caperteam.com>) a pioneering group in astronomy education research. Before long I began giving workshops myself on these teaching methods and became interested in how to assess their effectiveness. I began developing and reporting on results of rudimentary

assessment instruments during presentations at these workshops and other professional meetings.

During the winter of 2007, HFCC hosted a *NASA/JPL Center for Astronomy Education* (NASA/JPL CAE, <http://astronomy101.jpl.nasa.gov/>) *Teaching Excellence Workshop* (see <http://astronomy101.jpl.nasa.gov/workshops/>) given by Gina Brissenden and Edward Prather. That workshop served a dual purpose, also becoming the inaugural meeting of the CAE-*Great Lakes Regional Teaching Exchange* where I was designated as CAE-GLRTE coordinator (CAE Teaching Strategies <http://astronomy101.jpl.nasa.gov/teachingstrategies/>).

The point was first made at that workshop/meeting that, of the resources available for use in teaching introductory astronomy in an active and collaborative fashion, chief among them a manual of activities *Lecture-Tutorials for Introductory Astronomy* (Prather et al., 2007) there existed many tutorials on celestial motions (motions of the stars, the sun and the moon) and also light, spectra and stars but not as many as on topics in cosmology and the solar system. It was suggested that I might consider taking an active roll in the development of some of these activities.

During the 2007-2008 holiday break was when I first made contact with the *James Cook University Centre for Astronomy* (<http://www.jcu.edu.au/school/mathphys/astronomy/>) to explore the possibility of doing a Doctorate in Astronomy with research focused on astronomy education. Program Director, Dr. Andrew Walsh of the *JCU Centre for Astronomy* put me in touch with Dr. Carl Pennypacker of the Space Sciences Lab at the University of California-Berkley as my advisor. During the winter and spring of 2008, Dr. Pennypacker and I developed a proposal that became this project on the development and testing of active and collaborative learning materials focusing on solar system concepts through which we would also test the methods themselves. I officially enrolled in the program at the JCU Centre for Astronomy in the fall of 2008.

Since that time this project has also become part of a CAE –*Collaboration of Astronomy Teaching Scholars* (CATS) *Project* (CAE-CATS Projects, <http://astronomy101.jpl.nasa.gov/cats/projects/>) the *Solar System Concept Inventory (SSCI) & Solar System Lecture Tutorials Project* for which I am one of the collaborators. (CAE-CATS, <http://astronomy101.jpl.nasa.gov/cats/collaborators/>)

Abstract

The main goals of this project are; to develop and assess the effectiveness of learner-centered activities for introductory astronomy that focus on solar system topics and; to test the methods of learner-centered instruction themselves through the implementation of these activities and their assessments. The intended end of the project is to have developed entire solar system “unit” consisting of learner-centered activities on solar system topics that have been tested for their effectiveness

Since 2000, many resources for active and collaborative learning in introductory astronomy have been developed. This is especially true for two of the four the main sections of a traditional introductory college astronomy course, the observed motions in the sky and light, the Sun and stars. There is currently considered to be a dearth of activities pertaining specifically to solar system topics, also considered one of the four main sections of a traditional course. For instance, the leading *Lecture-Tutorial* (LT) workbook (Prather et al., 2007) has 38 LTs, 14 of them, 37% are about topics related to the observed motions in the sky and 16, 42% are topics related to light, the Sun and stars. Of the remaining 8, only 4, 11%, are about topics traditionally covered in a solar system unit, one each on the Earth’s surface, the formation of the solar system, the size and scale of solar system objects and extra solar planets. There are tutorials on planetary motion and gravity, but these are topics generally covered in the earlier motions and history unit. The last 4 LTs are about galaxies and cosmology.

Research investigating student pre-instruction beliefs and reasoning difficulties in cosmology, considered the fourth main section of a traditional astronomy course, is also underway as is the development and assessment of instructional materials. (CATS projects/ *Research on Students Beliefs and Reasoning Difficulties related to Cosmology* <http://astronomy101.jpl.nasa.gov/cats/projects/>)

Another reason for development of more material covering solar system topics is for research to better understand student learning in these areas. An assessment instrument the *Solar System Concepts Inventory*, SSCI that is under development and preliminary testing will eventually be used for this purpose. The availability of more material to assess will aid in the validation of the survey and then the survey itself will in turn aid in the development of even more new materials. (CATS projects / *Solar System Concept Inventory (SSCI) & Solar System Lecture-Tutorials Project*, <http://astronomy101.jpl.nasa.gov/cats/projects/>) Assessment instruments on light and spectra, the *Light and Spectroscopy Inventory*, LSCI (Bardar et al., 2007), and stellar topics, the *Star Properties Concept Inventory*, SPCI (Bailey, 2008), already exist and have been field tested (Bardar, 2008), used in research (Prather et al., 2008, Prather et al. 2009), and used to test instruction materials (Bardar & Brecher 2008, LoPresto & Murrell, 2009) as does a good amount of instructional material on these topics. (Prather et al., 2007). Assessment instruments on cosmology are also under development. (Wallace et al., 2011)

The activities developed, implemented and assessed for this project, in the order that they were assigned during a solar system unit, are;

1-*The HFCC Solar System Walk*

2-*Comparative Planetology*

3-*Formation of the Solar System*

4-*Extra-Solar Planets*

5-*Comets*

6-*Surface Conditions of Terrestrial Planets*

1-*Planetary Geology*

2-*Planetary Atmospheres*

A pilot research project that was designed and undertaken to test the viability of this project consisted of using active and collaborative instructional materials that were already in existence on other topics and testing them with an already existing and established assessment instrument. Based on the number of Lecture-Tutorials (LTs) available on the subjects of light, the Sun and stars (Prather et al., 2007) and the existence of an already established concept inventory, the *Star Properties Concept Inventory* (SPCI) (Bailey, 2008), light, the Sun and stars, usually the third “unit” of a general education introductory astronomy course, was chosen.

The experimental design of the different studies in this project is similar to that of the pilot project. In general, students were given pretest and posttest assessments so gains in groups receiving different methods of instruction could be compared. The scores of students who *did* the activities were compared to students that *did not* do the activities and were rather taught the same topics through more traditional lectures.

The assessment instrument used was the *Solar System Survey*, 25-item multiple-choice items on solar system topics developed and validated for this project to test the instructional materials developed and the instructional methods they employ

In efforts to minimize *instructor bias* and the *Hawthorn Effect* (Hake, 1998, from Slavin, 1992) different instructors involved in the studies were assigned to teach different sections both by lecture and by learner-centered methods. Also, in the final trials of each study, the author taught none of the sections involved.

The statistical significance of results were evaluated in two ways. When the performance of two groups on a set of assessment questions was being compared, the average score of each group and the standard error were calculated. The standard errors were considered the error-bars around each average. The less overlap in the error bars, the more significant the result. If there was no overlap the difference in the average scores of the two groups was considered statistically significant.

When the results of different groups on specific assessment items were compared the statistical significance of results were evaluated by chi-squared tests with 2 x2 contingency tables. The numbers of students giving correct and incorrect responses in each group were put into 2 x 2 contingency tables that were used to calculate. P-values. The lower the P-value the more significant the result, P=0.05 being considered the maximum value for a significant result.

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Figure 9.2.1 Histograms comparing planetary radii, masses and densities. Note-using logarithmic plots was considered, especially in the plot of planetary masses, where the only Jovian planet masses are even visible, but based on the fact that the course is non-mathematical in nature, it was decided that this may hinder the students' ability to draw conclusions from examination of the histograms.

Figure 9.3.1 Percentage of correct responses to each item in pretest (blue) and the posttest for lecture sections (red) and tutorial sections (yellow).

Figure 9.3.2 Normalized gains (Hake, 1998) for each item in the assessment from lecture (blue) and tutorial (red) sections.

Figure 9.4.1 Percentage of correct responses in the second part of the study to each item in pretest (blue) and the posttest for lecture sections (red) and tutorial sections (yellow).

Figure 9.4.2 Normalized gains from the second part of the study for each item in the assessment from lecture (blue) and tutorial (red) sections.

Figure 9.5.1 Percentage of correct responses in Fall 2010 to each item in pretest (blue) and the posttest for lecture sections (red) and tutorial sections (yellow).

Figure 9.5.2 Normalized gains in Fall 2010 for each item in the assessment from lecture (blue) and tutorial (red) sections.

Figure 10.3.1 The diagram of a comet's orbit that was given to students at the beginning of the class period in which comets were to be covered and at the beginning of the next class period after instruction. The following instructions were included; Figure 1 shows the portion of a comet's highly eccentric orbit that is close to the Sun. At each numbered position of the comet's *nucleus* draw the comet's *coma* (head) and *tail*. *Make sure that your drawing clearly shows any differences between the size of the coma and length of the tail and the direction the tail is pointing.*

Figure 10.3.2 Student drawing showing the common misconception that a comet always travels head first and tail last.

Figure 10.4.1 Student drawing showing correct variations in size of the coma and tail as well as correct orientations of the tail. Note- all students were taught in lectures that there are two tails on a comet but this was not considered part of this exercise (some students however did include two tails in their drawings).

Figure 10.4.2 Percentage of correct drawings for each item the diagnostic assessment (blue) and formative assessment in lecture sections (red) and in tutorials sections (yellow). Item 1 is the relative sizes of the coma; 2 the relative sizes of the tail; and 3 is the directions of the tail. Item 4 is the percentage in each group that made a drawing like Fig. 10.3.2, the head first, tail last misconception, so correct responses for this item will show a decrease.

Figure 10.4.3 Normalized gains, g , on items from the diagnostic to the formative assessment in the lecture sections (blue), and in tutorial sections (red).

Figure 10.5.1- Percentage of correct drawings for each item the diagnostic assessment (blue) and formative assessment in lecture-only sections (red) and in HPL/ visual-tutorials sections (yellow). Recall that item 4 is the percentage of students submitting a drawing like Fig. 10.3.2 showing the head first and tail last misconception, so correct responses for this item will show a decrease.

Figure 10.5.2-Normalized gains, g , on each item from pretest to posttest administration of the comets visual assessment, lecture-only sections (blue), and in HPL/ visual-tutorial sections (red). “Item” 1 is the relative sizes of the coma, 2 the relative lengths of the tail and 3 is the directions of the tail.

Figure 10.6.1- Percentages of students drawing the coma and tail size and tail direction correctly on Fig. 10.3.1 before (blue) and after instruction by lecture (red) and using the visual-tutorial (yellow) in the Fall and Winter 2010 and 2011 semesters. Recall that item-4 is the percentages of students submitting a drawing like Fig. 10.3.2 showing the common head first, tail last at all points in the orbit misconception.

Figure 10.6.2-Normalized gains, g , on each item from pretest to posttest administration of the comets visual assessment, lecture sections (blue), and in the visual-tutorial sections (red) during the fall and Winter 2010 and 2011 semesters. “Item” 1 is the relative sizes of the coma, 2 the relative lengths of the tail and 3 is the directions of the tail.

Figure 11.2.1-Visual Assessment used prior to and after instruction on detection of extra-solar planets (See Note 10.1).

Figure 11.3.1 Percentage of correct responses on the diagnostic, formative and summative extra solar planet visual-assessment for students given a lecture (blue) and doing a tutorial (red) on extra solar planets.

Figure 11.5.1 Percentage of students correctly identifying all the waveforms in item-1, item-2, and in both items on the extra solar planets visual-assessment on the pretest (blue) in lecture-only sections (red) and in HPL/visual- tutorial sections (yellow).

Figure 11.5.2 Normalized gains, g , on both items and the entire extra-solar planets visual assessment for lecture-only sections (blue), and in HPL/ visual-tutorial sections (red).

Figure 11.6.1 Percentage of students scoring 0-7 on the pretest (blue) and on the posttest in the lecture (red) and visual tutorial (yellow) sections.

Figure 11.6.2 Data from Table 11.6.2 showing the percent of students answering the entire front side (blue), back side (red) and the entire (yellow) visual assessment on the pretest and in lecture and tutorial sections during the Fall and Winter 2010 and 2011.

Figure 11.6.3 Data from Table 11.6.1. showing normalized gains on item-1 (front), item-2 (back) and the entire visual assessment in the lecture (blue) and tutorial (red) sections during the Fall and Winter 2010 and 2011.

Figure 12.7.1 Percent of correct responses before (blue) and after instruction on assessment questions on Terrestrial Planet surface conditions in sections receiving lecture (red) and doing the LT (yellow).

Figure 12.7.2 Normalized gains (Hake, 1998) on each item in the assessment of Terrestrial planet surface conditions in lecture (blue) and LT (red) sections.

Figure 12.8.1 Percent of correct responses on each item in the assessment of Terrestrial Planet surface conditions on the Pretest (blue) in lecture-only (red) sections and HPL (yellow) sections.

Figure 12.8.2 Normalized gains (Hake, 1998) on each item in the assessment of Terrestrial Planet surface conditions in lecture-only (blue) and HPL (red) sections.

Figure 13.6.1 Percent of correct responses before (blue) and after instruction on assessment questions on solar system formation conditions in sections receiving lecture (red) and doing the LT (yellow) in Winter 2009.

Figure 13.6.2 Normalized gains (Hake, 1998) on each item in the assessment of solar system formation in lecture (blue) and LT (red) sections during Winter 2009.

Figure 13.6.3 Percent of correct responses before (blue) and after instruction on assessment questions on solar system formation conditions in sections receiving lecture-only (red) and doing the LT as part of HPL-pedagogy (yellow) in Fall 2009.

Figure 13.6.4 Normalized gains (Hake, 1998) on each item in the assessment of solar system formation in lecture-only (blue) and LT as part of HPL-pedagogy (red) sections during Fall 2009.

Figure 13.7.1 Percent of correct responses before (blue) and after instruction on assessment questions on solar system formation conditions in sections receiving lecture (red) and doing the LT (yellow) in Fall 2010. The tutorial group out gained the lecture group on three items with gains appearing comparable on the other three.

Figure 13.7.2 Normalized gains (Hake, 1998) on each item in the assessment of solar system formation in lecture (blue) and LT (red) sections in Fall 2010.

Figure 14.3.1 Plot of student percentages scores on each item of the pretest (blue) and posttest in lecture (red) and tutorial (yellow) sections for the Winter 2009 *Solar System Survey*.

Figure 14.3.2 Normalized gain for each item in the lecture (blue) and tutorial (red) sections for the Winter 2009 *Solar System Survey*.

Figure 14.3.3 Percentage of students scoring 0-25 on the pretest (blue) and posttest in lecture (red) and tutorial (yellow) sections for the Winter 2009 *Solar System Survey*.

Figure 14.4.1- Plot of student percentages scores on each item of the pretest (blue) and posttest in lecture-only (red) and HPL-tutorial (yellow) sections for the Fall 2009 *Solar System Survey*.

Figure 14.4.2- Normalized gain for each item in the lecture-only (blue) and HPL-tutorial sections (red) for the Fall 2009 *Solar System Survey*.

Figure 14.4.3-Percentage of students scoring 0-25 on the pretest (blue) and posttest in lecture-only (red) and HPL-tutorial (yellow) sections for the Fall 2009 *Solar System Survey*.

Figure 15.3.1-Plot of the results of *Student Attitude Survey*.

Chapter 1

Introduction

1.1 Statement of Problem

The question being researched is whether or not use of the learner-centered activities on solar system topics developed is a better way to teach these topics than by traditional lectures. The results will also bring into question whether or not active and collaborative learning is in fact more effective than lecturing. The validity of the results will also depend on the quality of the activities and validity of the assessment, both of which must be determined to some degree as well.

1.2 General Overview

Chapters 2-5 are the background for the project, the results of a literature search on how people learn and active and collaborative learning in general, then, more specifically, how students learn science, how active and collaborative learning is applied to introductory college astronomy. Chapter 6 is an overview of course the solar system unit of which the instructional materials developed are a part. Chapter 7 outlines the results of a pilot research project that employs the intended methods of this project using already developed material for instruction and assessment on the subject of light, the Sun and stars. Chapters 8-14 describe the development and implementation of the instructional materials and assessments used in the project and their results. Chapter 15 is the results of a survey of student attitudes. Chapter 16 is the conclusion.

Chapter 2

How People Learn

2.1 Introduction

The Committee on Developments in the Science of Learning released a report in 2000 on what they termed as the “New Science of Learning” in the form of the book, *How People Learn*, published by the National Research Council. (Bransford et al., 2000) Their findings resulted in recommendations that educators pay close attention to three specific things; *what* is taught, *how* it is taught and how it is *assessed*. The goal of education being to help students develop the skills necessary to both acquire knowledge and think for themselves, to “learn how to learn” and ultimately become “life-long learners.” This also included educators developing new approaches in attempt to help students develop these skills.

2.2 Learning Environments and the Principles of How People Learn

The committee’s recommendations were organized into three principles of how people learn. These were based largely on the idea that settings greatly influence learning and the way these principles can be applied for effective instruction. The “*Principles of How People Learn*” or “*HPL principles*” are: 1-that students come to classrooms with existing understanding based largely on their experience and that these understandings must be engaged before new learning can occur; 2-that factual knowledge must be organized into conceptual frameworks to be readily accessed then understood; and 3-that instruction should be based on attempting to have students take control of their own learning, largely through well defined goals and frequent monitoring of progress.

These principles are used to define recommended settings or “*Learning Environments*” in which they can be applied to design effective instruction. Recommendations are that instruction be; *learner centered, assessment centered, knowledge centered and community centered*. These principles and environments will be referred to for short

throughout this work as the “*HPL principles*,” and “*HPL environments*” or together as “*HPL pedagogy*.”

2.3 Learner Centered Environments

The basic idea of a “*Learner Centered Environment*” is that instruction start with attention being paid to what students bring with them to the classroom. What students know, the skills they posses and their attitudes and beliefs should all be brought out. This can occur either formally, through diagnostic assessments, or informally, through discussion. Discussions should not deny beliefs. This pertains particularly to the abundant misconceptions students usually have. Misconceptions are very robust and persistent. Students almost always hold on to misconceptions if simply *told* that they are wrong. Student minds are *not* “blank slates” or “empty vessels” onto or into which new knowledge can be either etched or poured. Rather, students have a logical system based on experience that has sufficed and been re-enforced all of their lives. Hence, it is against this discouraging backdrop that education must work. Therefore, misconceptions need to be drawn out and dealt with. Students almost certainly need to *see* their preconceived notions fail before the misconceptions can be overcome. Interactive demonstration, ones in which students are first asked to make predictions based on their prior knowledge and then can participate in some way and actually witness the failure of their preconceptions is a first step toward conceptual change. Simply put, these activities build new structures in the brain, so when new data is perceived, they then can jump from the old, likely flawed preconception to a more scalable model. We then allow them to build a new model that is connected in their experience with the data through the old model.

This leads directly to the conclusion that for many students conventional lectures, simple “teaching by telling” does *not* work. Research conducted by Nobel Prize-winning physicist, Carl Wieman (Wieman, 2009) showed that retention by students of facts presented in lectures after 15 minutes is only 10% and that of physics graduate students and faculty is *not* any better. This is a startling conclusion, and a corollary to this

statement is that much of our college education system is flawed and not working at its best efficiency. Indeed the college admission process may select out students who can learn *enough in spite of* a bad teaching system. But imagine if even “successful” students could become much more efficient and better learners. One might say that college education only succeeds because the good students can dig their way out of any mess. Typical instruction is probably not in their best interest. The central thesis of HPL and what we submit evidence for in this work is that students can often gain better understanding from more active-learning, such as inquiry-based exercises, where they are actually doing something rather than just attempting to listen to someone explain concepts. We propose that traditional, lecture-based teaching methods are literally out of date. Useful activities are often tasks intended, at least partly, to get students to think about their preconceptions, something that lectures are not often designed to do. This approach can help lead students gaining control of their own learning.

2.4 Knowledge Centered Environments

A “*Knowledge Centered Environment*” is one where instruction is centered on: 1-*what* the subject matter is; 2-*how* it is being taught (the curriculum); and 3- how mastery of the subject will be identified, or *what* students should *know* or be able to *do* (the learning goals). The goal of conceptual knowledge-centered instruction is the deep understanding of concepts, the big themes of science rather than simply the memorization of seemingly disconnected facts. If only memorized, facts are not useable knowledge. Rather they must be organized into a conceptual framework and used as examples to support the learning of concepts. Students generally are in need of help to achieve this. What is most important in a topic, the core concepts, is often not obvious to students. Too much unorganized factual information overwhelms and confuses students and prevents them from seeing “the big picture,” or “the forest through the trees.”

Knowledge-centered instruction also involves covering *less* material, but in *more* detail, with more depth, avoiding the “mile-wide, inch-deep” approach to a subject. As recommended in learner-centered instruction, having students doing inquiry-based activities rather than listening to lectures can lead to deeper understanding, fostering the knowledge-centering approach. Many instructors do not undertake such teaching because it usually takes more class time. However, students can learn more if curricula are organized centering on activities designed to use facts to support the understanding of concepts rather than simply a barrage of these facts to be memorized and most likely later forgotten.

2.5 Assessment Centered Environments

Most assessment occurs in the form of quizzes, tests and examination, typically with the purpose of final evaluation with which to assign grades. This “*summative*” type of assessment is important, but since it occurs after instruction is concluded it is too late for students to revise or add to their knowledge and thus aid in any more learning. An “*Assessment Centered Environment*” makes use of assessment types beyond testing, including both “*diagnostic*” and “*formative*” assessments that are responsive to student progress.

Diagnostic assessment occurs prior to any instruction on a topic and can, as is desirable in learner-centered instruction, draw-out student preconceptions and make their thinking visible to themselves, their peers and the instructor. Formative assessments, can do this as well, but occur during instruction. They provide feedback for the students, allowing them to monitor their own progress, and also for the instructor, to monitor progress while there is still time for students to amend their knowledge. Any information about students’ previous knowledge can be used to everyone’s advantage. Formative assessments should occur frequently and, as in knowledge-centered instructions, involve questions about understanding concepts pertinent to instructional goals and *not* just memorization of facts. Much work on “embedded assessments” to which these could also be referred, has

been undertaken over the last decade (Wilson & Sloan, 2000), showing consequent improvement in student learning.

Well-written multiple-choice questions can serve this purpose. This idea is in contrast to some of the trends in modern education, such as assessment of conceptual understanding, through machine-readable essays. However, the “Force Concept Inventory” (Hake, 1998) is a well-established example of such a multiple-choice assessment of conceptual learning. This is especially true of multiple-choice assessments in which the incorrect responses (the distracters) involve common misconceptions about the topic. This of course necessitates prior identification of these misconceptions.

Effective assessments are usually not in the form of a test or quiz taken individually or a paper or questions assigned as homework, but something more learner-friendly that occurs in the classroom and involves student interaction, often in the form of small group discussion or students evaluating each other’s work or both.

2.6 Community Centered Environments

A “*Community Centered Environment*” is defined as a classroom environment that promotes students working together and building on each other’s knowledge as they cooperate to solve problems. The “norm” in such an environment should be a culture of respect in which students are encouraged to ask questions and share ideas. Learning to explain the reasoning behind their understanding is essential for the student and their peers, so it should be encouraged. Students should therefore be made to feel free to communicate their understanding while trying to learn concepts. In this environment, there are no mistakes – just evolving models. Students should not have to worry about being criticized or ridiculed for incorrect or I answers. Making a mistake should *not* be considered an admission of inadequacy, but rather a helpful opportunity to search for deeper understanding.

Research has shown that students almost always gain motivation and therefore improve their performance from seeing that their contributions impact others' learning in a positive way. (Bransford et al., 2000) Strategies that can be used to foster community-centered instruction are collaborative learning activities, ones in which students work together on learner-centered, inquiry-based projects, and reciprocal teaching. For instance, having students explain concepts from the previous class session to one another as a review. Also, since the success of a community-centered environment will be based on mutual respect and trust, it is usually counter-productive to have students competing with one another for grades on a curved scale.

2.7 An Example

Clearly, there are overlaps in the four environments in which the three HPL principles are applied. An example of a pedagogy that combines all four of the HPL environments is posing multiple-choice questions as formative assessments to students in a classroom-response format. This can be done with either with an electronic system or flashcards. A question is projected on a screen for all to see then, after having had sufficient time to read the questions themselves and think about their response, a vote is taken on the correct answer. If a large majority of students answer the question correctly, the instructor can consider the material learned and the class can then move on to another topic. If not, students are then required to seek out others who had answers different than their own and discuss the question while trying to defend and convince others of their choice. Once discussions quiet down or turn to other matters, another vote can be taken to see if the percentage of correct responses has increased.

This pedagogy, dubbed "*peer instruction*," (Mazur, 1997) was pioneered and championed by Eric Mazur (Mazur, 2002) of Harvard. Nobel laureate Leon Lederman also developed such a system. (Pennypacker, 2010) Mazur found that students of introductory physics that had been given lectures on Newton's laws of Motion could recite the laws but could *not* actually put them to use in answering simple conceptual questions. This made him

realize that lectures are really only a transfer of information from the teacher to the student that sometimes even occur without the information passing through the brains of either. This prompted him to begin to shift the responsibility of gathering information to the students by assigning them reading before class and using class time for discussion of and thinking about the material through the use of peer instruction. He also refers to this as teaching by “questioning” rather than “telling.” Research has shown (Lasry et al., 2008) that when instruction focuses on engaging the students, conceptual gains will be much higher than with instructor-centered lectures.

Also often referred to as “*clickers*,” the use of a classroom-response system has been embraced by many in the learner-centered teaching of astronomy. (Duncan, 2006, 2007, 2008: see Pasachoff et al., Prather & Brissenden, 2009) This application will be discussed in more detail in chapter 5 and results that include its use are reported in chapters 7, 9, 12 and 13.

When executed well and with adequate classroom management, the use of “clickers” is learner centered because the student is actively engaged in reading and thinking about the answer to the question. Their use can also be knowledge centered if the questions used are written to test understanding of a concept rather than memorization of facts. When used as formative assessments for student to monitor their progress while still allowing them to revise and improve their thinking and to give the instructor feedback, the exercise is assessment centered. This pedagogy is also obviously community centered since during the discussion portion the students are collaborating, learning from each other and exchanging ideas.

2.8 Instructors

A challenge for instructors is to recognize that being an expert in the content of a subject is only the *first step* to good teaching. Unless one addresses explicitly and implicitly the preconceptions of the students, HPL claims and evidence supports that teaching will work at much lower efficiencies. A deep understanding of the content being taught is a must, but knowledge of effective pedagogy is essential as well. Using innovative methods of instruction that are part of HPL Pedagogy, such as formative assessments and active and collaborative learning can cause both student thinking and difficulties to be more transparent and instruction more successful.

Chapter 3

Active & Collaborative Learning

3.1 Introduction

When considering the HPL (*How People Learn*) principles and environments pedagogies that employ everything discussed thus far are *Active & Collaborative Learning*. Research has shown that students learn best when actively engaged in the process. This is also true of students working in collaborating groups. Not only do they learn more, they have longer retention and enjoy the learning process more than when the same material is taught thorough formats such as traditional lectures. (Beckman, 1990; Chickering & Gamson, 1991; Collier, 1980; Cooper, 1990; Goodsell, Johnson & Johnson, 1989; Johnson, Johnson, & Smith, 1991; Kohn, 1986; Slavin, 1980, 1983; Whitman, 1988)

3.2 Active Learning

As mentioned above and in Chapter 2, (Lasry et al., 2008) research has shown that when instruction focuses on engaging the students, conceptual gains will be much higher than with instructor-centered lectures.

In active learning, it is not information, but the actual process of learning, and thus the responsibility for it is transferred from the teacher to the student. (Aronowitz, 1993, Boud, 1981) Students need to be *told* less and encouraged to *discover* more. (Weimer, 2002) The transfer of information through lectures makes students more dependent and discourages more meaningful approaches to learning. In addition, with the advent of media such as YouTube™ (www.youtube.com), lectures are becoming rapidly obsolete. When some faculty at the University of California began putting their lectures on YouTube,™ (www.youtube.com/user/UCBerkeley) students stopped coming. (Pennypacker, 2010) Hence, mandatory attendance soon became a requirement.

Students should be developing individual ways of understanding. Instructors need to allow learners to raise questions that test their own ideas for validity and students need to be involved in the process of acquiring and retaining information. They should be exploring and handling data on their own and relating it to their experiences, when actively engaged in discovery the students actually become scientists themselves. It is in this way that students can become more independent in their learning. (Boud, 1981)

Short innovative activities, creatively designed to engage students in content should become routine. Questions generated by such material will create “teachable-moments” that often do not occur in other, less-active learning environments. (Weimer, 2002). The materials presented and assessed in Chapters 8-13 of this work are all designed exactly to fulfill this purpose. A teaching environment in which active learning occurs is the HPL learner-centered environment (Bransford et al., 2000) discussed in the last chapter.

3.3 Collaborative Learning

Collaborative learning can be defined as students, often of varying levels of skill and academic achievement, working together in small groups where they are responsible for each other’s learning with the purpose of completing a task or achieving a goal. (Gokhale, 1995)

The value of students working in groups to learn from one another as they discuss and attempt to solve problems is often underestimated. Research has shown that they do indeed learn from one another. (Qin et al., 1995) Students should be encouraged to work in groups as research has also shown that problem solving skills often improve when students are able to better visualize a problem when presented with another student’s perspective or interpretation other than their own. (Brunner, 1985) This can result in higher achievement and retention (Johnson & Johnson, 1986) as a result of greater engagement caused by an increased responsibility for not only their own, but the group’s learning. (Trotten et al., 1991)

Collaborative learning has even been credited with an increase in critical thinking skills. In one study (Gokhale, 1995) students who worked in groups showed significantly greater gains on conceptual questions than students who worked as individuals. Interestingly the groups did *not* do significantly better than individuals on assessments of more fact-related material. This observation shows a link between collaborative learning, a HPL community-centered environment, with the more concept, less fact-centered HPL knowledge –centered environments (that will be discussed further in the next section) discussed in the last chapter. (Bransford et al. 2000)

In the same study (Gokhale, 1995) a survey showed that students liked working in groups. There were many more positive comments, 107, about it than negative, 2. The only negative comment was that sometimes explaining things to other students was a waste of time. Positive comments included that pooling knowledge and experience was fun and helped create a more relaxed atmosphere that made problem- solving easier and that getting new perspectives and feedback helped stimulated thinking and helped in understanding,

3.4 The Role of Content

There is much more knowledge in any one field than can be taught by any one instructor in any one course. Students need to be able to continue learning on their own. So instructors need to not just *cover* content, but rather *use* the content (Finkle, 2000) to teach the students to do this. Content is central, but it is more meaningful when students are actively engaged in acquiring the knowledge and using strategies and techniques for collecting and analyzing data rather than simply hearing about what others have done and how they did it. (Stage et al., 1998) Less material will be covered, but the trade-off is that it will be covered with more understanding and students will be developing skills that will allow them to continue to learn more about the subject after the class has ended. Learning should involve a qualitative change in knowledge more so than a quantitative change. (Ramsden, 1988)

This is well aligned with a statement being considered in the resolution of *Commission 46, Astronomy Education and Development*, of the *International Astronomical Union* (IAU): “That astronomy, when properly taught, nurtures rational, quantitative thinking and an understanding of the history and nature of science, as distinct from reproductive (rote) learning and pseudo-science” (Pasachoff & Percy, 2005, <http://iaucomm46.org/content/considering>) Commission 46 and its work as relevant to this study will be discussed in more detail in Chapter 5 and cited in other parts of this work.

This is also very well aligned with the HPL knowledge-centered learning environment, discussed in the last chapter, that stress to *use* of facts *rather than* their memorization, to teach concepts. (Bransford et al., 2000)

3.5 The Role of Assessment

As discussed in the example of classroom response system, or “*clickers*,” in the previous chapter, assessments, especially formative ones can be both active and collaborative. Students voting on the correct responses is active and discussions that occur if not a high enough percentage of students respond correctly is collaborative. Although they are an excellent example of the HPL assessment-centered environment as well as community and learner-centered environments discussed in Chapter 2 (Bransford et al., 2000) “Clickers” are not the only type of active and/or collaborative assessment, there are in fact many methods that can be employed. (Keeley & Sneider 2012)

Students can be given mini-quizzes, on an important topic from the previous class meeting and grade and discuss the answers to each other’s papers. They can also be asked to choose partner to which they will be instructed to explain an important concept from the previous class meeting and the partner then will be asked to do the same with another concept . Students can also be instructed to write a very short paper at the end of the class period, to limit the length, about the “muddiest point” from that day’s class the idea or concept that had the most difficulty with or understood the least. Collecting and reading

these before the next class period will give the instructor instant feedback about what is and is not getting through to students, which will allow for further instruction for clarification or if necessary, changes in the instructional techniques. (Paulson & Faust, 2010 <http://www.calstatela.edu/dept/chem/chem2/Active/>, Keeley & Sneider, 2012)

Most formative assessments should be “low stakes,” meaning, usually *not* for credit. This will reduce student anxiety about a grade and will likely make them perform better, resulting in a more honest of they do and do not know. (Weimer 2002)

3.6 The Role of the Instructor

One of an instructor’s ultimate goals should be to teach students to think for themselves, so that they become more self-directed and independent and responsible for their own learning. These are skills that can also be useful in their personal and professional lives long after they leave school. (Baud, 1981) Classrooms that are too centered on the instructor arguably have an imbalance of power that negatively effects learning. The power needs to be shared more equitably between the teacher and students. This will empower the student to become more autonomous in their learning. (Ayers, 1986)

The instructor is of course essential, but needs to step aside and be more “around” the classroom than “in front” of it. This means becoming more of a “guide” or “facilitator” or a “resource” for a collaborative learning community. (Barr & Tagg, 1995, Hill, 1980) This also necessitates knowing when to “hang-back” and let the students lead. This is not to say that it is less work for an instructor. It can actually be far more work, because it requires more preparation and can be a much harder method of instruction than by traditional lectures.

The role of the instructor could be considered similar to that of a coach, gardener or conductor. A coach designs practice, sets the game plan, tries to motivate the players, sends in the plays and even makes decisions during a game, but I *players* that actually have to play. (Dunn., 1992) A gardener seeds and cares for a garden, but the plants have

to grow on their own. (Fox, 1983) A conductor (be it of a philharmonic or a community band) cannot play for the musicians. In all cases, the instructor sets the stage, but it is the students who actually have to undertake the work. (Eisner, 1983)

Instructors must act as examples, directing learners in how to solve problems and develop better understandings *on their own*. (Black, 1993) Instructors can show the way, even point out the sights, but again, they *cannot* make the trip for the students. Students must accept the responsibility to develop the skills and awareness to become independent learners. The instructor's job is to create and maintain the conditions, the learning environments, necessary to promote this. (Weimer, 2002) The instructor can help organize and make a map to guide the student through materials, but it is the students who undertake the journey. (Weimer, 2002)

This includes connecting students with learning resources and designing activities and assignments should be the vehicles for student learning. Activities and assignments that engage and motivate learners, which requires ingenuity and creativity. (Weimer, 2002) As mentioned previously the materials presented and assessed in Chapters 8-13 of this work are all designed exactly to fulfill this purpose.

This should also includes using instructional time to teach skills. This should not be considered “below” an instructor or diminishing the content of a course., rather it should be an integral part of a course and not an extra that is simply “added-on” or “fit-in.” (Weimer, 2002)

3.7 Challenges for the Instructor

Stepping aside and letting the students lead can be difficult for many instructors. It is hard to resist “showing what you know,” or being the “Sage on the Stage “ rather than the “Guide on the Side.” (King, 1993) It is far much easier and, for some instructor more satisfying, to give a quick, “snap,” answer to a student's question, but this is not always in the student's best interest. It is also difficult to admit that there is no guarantee of

success, that learning cannot be forced, but rather that it is a student decision. “You can lead a horse to water, but you cannot make them drink.” In learner-centered instruction, it can also be hard to deal with the “messiness” (Weimer, 2002) involved when students do not do something well. Instructors must stop doing things *for* students, do less telling and allow more discussion and discovery to occur. Students, almost inevitably, want to be told the answer, as this is how they have been taught all of their lives. Also, allowing what students do and do not learn must drive instructional decisions. This requires frequent feedback, usually formative assessments that also involve the students monitoring their own learning.

Chapter 4

How Students Learn Science

4.1 Introduction

In 2005, the National Research Council released *How Students Learn-Science in the Classroom*, (Donovan & Bransford, 2005) a follow up to *How People Learn* (Bransford et al., 2000) pertaining specifically to the application of the HPL principles and environments (HPL pedagogy) to teaching science. New guidelines resulted in recommendations for effective science instruction. The guidelines are that students be assisted in: becoming familiar with the concepts and theories of scientific disciplines (*what we know*); understanding how scientific knowledge is attained, (*how we know it*); and the ability to use the understanding to engage in inquiry (*doing science*). These guidelines lead to recommendation for effective science instruction that are aligned with HPL pedagogy: that student preconceptions be addressed; that students be taught what it means to “do” science; and that students be encouraged and given the opportunity to reflect on what they have learned. These three recommendations together will henceforth be abbreviated as the “*HSLS recommendations*.”

4.2 Addressing Preconceptions

This recommendation is aligned directly with first of the HPL principles and addressed by three of the learning-environments. Students have preconceptions about science rooted in their everyday knowledge and experience that are often sensible, but are not scalable beyond a narrow range of input data. Examples are that forces are properties of objects rather than interactions between them, that objects “are” certain colors rather than reflecting those colors (or wavelengths) of light. One physics instructor reported that despite having “covered” gravity, many students in his physics class believed that objects in the room were held on the ground by the weight of the air and would float away if the air were pumped out of the room. Students may also have preconceived ideas about how

science is done. Most students do not understand that science is a process of inquiry and not just a body of knowledge or facts and figures that lead to right or wrong answers. (Donovan & Bransford, 2005) In an assessment-centered learning environment, science instruction should start with discussion or activities meant to draw what students think they know and how or why they know it. As in a community-centered environment, this can be done in groups with a culture of respect, where questioning is valued and errors are looked at as learning opportunities. Since students are active participations in this process, it is also an example of instruction in a learner-centered environment.

4.3 Preconceptions in Astronomy

As was clear from *A Private Universe* (Harvard-Smithsonian Center for Astrophysics, 1987) that begins by showing interviews with Harvard students at their graduation that students hold many interesting theories about nature and the Universe. There has been much work done on preconceptions and misconceptions in astronomy showing that they are rampant. (Sadler, 1992, Zeilik et al., 1998, Comins, 2001, Plait, 2002 Zeilik & Morris, 2003, Fucili, 2005, see Pasachoff & Percy, Metaxa, 2008 see Pasachoff et al.) A recent study at HFCC (LoPresto & Murrell, 2011) showed that among other misconceptions that 79% of N=528 incoming introductory college astronomy students believed that varying distance between Earth and the Sun is the cause of the seasons, that 74% believe that the North Star is the brightest star in the sky and that 71% believe that lunar phases are caused by Earth's shadow being cast on the moon. These and a number of other misconceptions revealed by the survey support HPL teaching by showing that dealing with preconceptions must become an integral part of the instruction of introductory astronomy if it is expected to be successful.

4.4 Doing Science

Simply telling student about scientific knowledge or principles is not sufficient for effective science instruction. (Donovan & Bransford, 2005) In order to gain understanding they should experience science through a modern, controlled, evidence-based process. This likely cannot be achieved by simply lecturing to students on the steps of the scientific method then instructing them to apply the process to an experiment during a laboratory period, nor can it be achieved by giving students “lock-step” or “cookbook” procedures to follow to attain a certain result. Rather, groups of students should be engaged in active inquiry. The inquiry should be guided to give them the knowledge necessary to understand concepts, but they should be encouraged to figure things out for themselves and experience the excitement of discovery, with the ultimate goal being conceptual change. This recommendation is aligned with the second and third HPL principles and with the learner, knowledge and community centered environments. (See also, Percy, 2008, see Pasachoff et al., 2008)

4.5 Opportunity for Reflection

Based on the third HPL principle and the learner, assessment and community-centered environments, students must be given the opportunity to reflect on what they have learned. Formative assessments, as in the example in the previous chapter of using a classroom response system, are among the most effective ways to provide this opportunity. They allow students to test their understanding by responding to questions about topics, then discuss their answers, and ask questions about them while there is still time to revise and improve their thinking. Also, as with assessing preconceptions, this should be in a classroom with a well-established community-centered culture of respect. This is a first step in students taking control of their own learning and becoming independent learners. Feedback is also valuable to the instructor, showing how much progress is being made toward the learning goals and, if necessary, allowing for adjustment of instructional plans in response.

Chapter 5

Learner-Centered Teaching in Introductory College Astronomy

5.1 Introduction

Since the year 2000, the principles and environments of *How People Learn* (Bransford et al., 2000), especially learner-centered teaching (Weimer, 2002) have been gaining popularity in the instruction of introductory astronomy at colleges and universities. One of the courses in which HPL-pedagogy has been used extensively is the college introductory astronomy course. Often referred to as “Astro 101,” (Slater & Adams, 2003) it is taken every year by approximately 250,000 students at a majority of the colleges and universities in the country. (Fraknoi, 2001, Lomb & Stevenson, 2008: see Pasachoff et al., 2008, Prather et al., 2009) It usually fills a general education science requirement or is an elective. Astro 101 used to be largely a slide/transparency show accompanied by lectures with an emphasis on the memorization of facts. However, for many, this has changed and it has become more concept-driven and is now the focus of much educational research.

A manual, *Learner-Centered Astronomy Teaching: Strategies for ASTRO 101* (Slater & Adams, 2003) stresses three ideas; 1-that students have preconceptions that must be attended before meaningful learning can occur; 2-that students need repeated exposures to complex ideas; and 3-students require frequent feedback from instructors in order to monitor their own progress. The professor is referred to as a guide rather than the “central-dispenser of knowledge.” It is also recommended that instruction require that students be less passive and more active, participating in collaborative group learning. These ideas are clearly inspired by the HPL principles and environments (Bransford, et al. 2000) and the HSLS recommendations. (Donovan & Bransford, 2005) The manual goes on to identify “*Principles of Good Practice*” for undergraduate education. These are; encouraging student-faculty contact, cooperation among students, active-learning, giving prompt feedback, emphasizing time on task, communicating expectations and

respecting different ways of learning. (Slater & Adams, 2003, adapted from Chickering & Gamson, 1987)

Many of these ideas have also been expressed in papers and posters given at meetings of the International *Astronomical Union* (IAU) Commission 46. (<http://iaucomm46.org/>) Much of the educational research and resolutions adopted as a result of the meetings are outlined in *Teaching and Learning of Astronomy: Effective Strategies for Educators Worldwide* (Pasachoff & Percy, 2005) and *Innovations in Astronomy Education*. (Pasachoff et al., 2008) More specifically these include that many students come to introductory astronomy lacking proper background, with misconceptions and require being taught by more hands-on methods (Metaxa, 2008: see Pasachoff et al., Fucili, 2005 see Pasachoff & Percy) and that they should not just be told about science, but rather be given the opportunity to actually do science. (Fucili, 2005, Percy 2005 :see Pasachoff & Percy)

5.2 Assessment

An article on the role of assessment in introductory astronomy (Brissenden et al., 2002) states that “assessment drives student learning.” It recommends conceptual diagnostic tests prior to, during, and after instruction. These can be the diagnostic, formative and summative assessments of the HPL, assessment-centered environment. (Bransford et al., 2000) It also states that the real value of assessment is to improve learning and to harness its true power, assessment should occur while learning is still in progress. This is formative assessment. Attitude surveys are also recommended. These are assessments that can gauge the perceptions of students and their opinion about the subject, the course, and the instructional methods. The results of such “affective” data taken for this project will be discussed in chapter 14.

5.3 Classroom Response Systems/“Clickers”

Classroom response or “clicker” questions are a direct application of the pedagogy used as an example in chapter 2 of combining all four of the HPL environments. Pioneered in physics education, (Mazur, 1997) they have become very popular and shown exceptional promises as a tool for active and collaborative learning in introductory astronomy. (Duncan, 2006, 2007, 2008: see Pasachoff et al.)

This format for asking multiple-choice assessment questions makes use of an electronic-response system or a less expensive set of flashcards with the letters of the choices printed on them, preferably in different colors. Students use either system to vote on the answers. There has been research that suggests that the colored flashcards can be used just as effectively as the electronic system (Prather & Brissenden, 2009; Lasry, 2008). When posed as diagnostic assessments prior to instruction, they allow students to see what they will be learning or what they will be expected to know. This is true even if the answers are not revealed at that time. This also gives the instructor an idea of how much the students initially know about a topic, which is often very little.

After a first attempt at instruction, similar or even the same questions are asked again, often at the beginning of the next class period. They are now formative assessments meant to give the students and the instructor feedback. At this time, *while there is still the opportunity to do so*, whether student knowledge needs to be added to or revised can be determined. (Bransford et al., 2000, Weimer, 2002, Mazur, 2009) If less than about two-thirds to three-fourths of students respond correctly to an item, they are asked to find at least one other student who answered differently than they did and discuss or debate the question. After discussions die down or start to turn to other topics, the instructor calls for another vote. The second vote will often show dramatically improved results, sometimes nearly 100% agreement on the correct response. If a two-thirds to three-fourths or more majority of correct responses is achieved, then it is time to move on to the next topic. If *not*, more instruction on the current topic is required. (Mazur, 2009, Duncan, 2007)

This is an excellent example of allowing what students do or do not learn drive instructional decisions. (Weimer, 2002) Student discussions of this type are a version of “peer-instruction.” (Green, 2003, Mazur 2007, James et al., 2008) They are also often referred to as “think-pair-share.” (Slater & Adams, 2003) Affective data from “attitude surveys” (Brissenden et al., 2002) shows that students consider this well spent class time that helps them learn and research confirms that this is the case. The success of using “clicker” questions in this capacity is well documented. (Duncan, 2007, Lasry et al., 2008, Mazur, 2009, Prather & Brissenden, 2009)

It has also been shown that when student discussions are “high-stakes,” meaning for points or a grade, they are more likely to be dominated by one student. The student perceived by the group as the “smartest” or “best” student. If discussions are more “low-stakes,” not formally evaluated, more students participate and thus experience greater benefit. (James et al., 2008)

5.4 Lecture-Tutorials

LTs Defined

Lecture-tutorials (LTs) are collaborative learning activities written for non-science majors with little mathematical background. They have become very popular for use in general education introductory astronomy courses (Prather et al., 2007) and other subjects as well. (Kortz & Smay, 2010) They are designed for students to actively work with and discover concepts for themselves rather than being lectured to about them. LTs consist of a series of short questions that build on one another, including questions addressing common misconceptions. (Slater, 2008: see Pasachoff et al.) They were originally designed for use in large lecture-hall sections with hundreds of students, but can be used, perhaps even more effectively, with smaller sized classes. (Prather et al., 2005)

Using LTs

The recommended method for use of LTs (Prather et al., 2005, Slater, 2008: see Pasachoff et al., Prather & Brissenden, 2009, *Lecture Tutorials*) is to start with a short introductory lecture on the topic being covered to set the stage for the LT. The students are then asked multiple-choice questions about the topic that are designed to show them what they need to learn. This is likely best accomplished with a classroom- response system or “clickers,” (Duncan, 2006, 2007, 2008: see Pasachoff et al.) as previously discussed.

Next, students do the LT in small groups with the instructor (and assistants, if available, for larger classes) circulating around the classroom to answer questions. LTs are generally designed to only take students about 20 minutes (or about 5 minutes per page) to complete and it is recommended that the instructor “enforce” time limits. One way to do so subtly is to stop the class and ask a question specific to the part of the LT that they are expected to have reached by that time. After completion of the LT, a short wrap-up lecture or debriefing is recommended.

The reason for enforcing time limits when working LTs is two-fold; if given too much time to complete a task, student discussion may tend to wander off the topic, wasting precious class time, i.e. “time on task.” (Slater & Adams, 2003, adapted from Chickering & Gamson, 1987) Second, since the use of LTs *takes* class time, their use is likely already at the expense of the coverage of other material so expediting their completion minimizes this effect. (Prather & Brissenden, 2009, *Lecture Tutorials*)

Another reason for the instructor needs to circulate around the room is to listen for conversations that turn to topics other than the task at hand. This is a sign that either students are ready to move on or that they are not focused on the task. In either case, students should be politely encouraged to return their attention to the LT.

There will almost always be some students during instruction with LTs (and also during the discussion portion of the use of “clickers”) who will choose *not* join in group work or discussion. These students should be encouraged to do so. One bit of positive reinforcement that may persuade them to work with others is tell them that they may be able to help others in a group, that the others may want to hear what they have to say. If this does not work, however, attempts to force or otherwise compel students who still choose to work alone, probably should *not* be made. (Slater, 2004)

After completing the LT, students should again be asked questions, again preferably in a classroom-response format, about the topic to determine what has been and what still needs to be learned. As described in the use of “clickers,” if a satisfactory majority does not initially answer a question correctly, there should be group discussions and another vote afterward. It is often useful to do this at the beginning of the next class period after the LT was done. This gives time for concepts to “sink-in” and it can be seen how well they were initially retained. Students that did not finish the LT in class can be instructed to finish it prior to the beginning of the next class meeting. (Prather & Brissenden, 2009, *Lecture Tutorials*)

An Example

Chapter 12 will outline the development, implementation and assessment of an LT about the surface conditions of terrestrial planets. The class period in which it is used would begin with a short lecture of less than 20 minutes, identifying the size and mass of a planet and its initial temperature, a function of its distance from the sun, as the two main factors that will control the geological and atmospheric evolution of planet. Geological activity, such as volcanism and tectonics, cratering from impacts, and erosion would also be identified as the processes that affect a planetary surface during its evolution. The lecture should not go into detail about the evolution or conditions of the individual terrestrial planets, as this is what the students will discover when doing the LT.

Next come the classroom/response/clicker multiple-choice questions. Since designed to show students what they will need to learn, they could cover some of the material in the introductory lecture but also some should be about what they will encounter in the LT.

Examples would be asking whether size or distance from the sun is a more important factor in whether or not a planet would be geological active or retain an atmosphere. Or giving the planets as the choices and asking which would have geological activity going on for the longest or the least amount of time or which would have the thickest or thinnest atmosphere. Asking students to choose the reasons that Mars' atmosphere is so thin, or why Mars is so cold or what caused Venus to be so hot are appropriate questions as well.

The students separate into groups of 2 or 3 to do the LT while the instructor circulates around the classroom both answering and *asking* questions in order to help students complete the exercises. Again, after being encouraged to join the small groups, students who still wish to work alone should be permitted to do so. Listening to student discussion to make sure they stay on task and are the right track and intervening if necessary to put them there is also a good strategy as well. Since LTs should not take more than about 5 minutes per page, another good strategy is to subtly move things along by asking the entire class an answer to question that is as far into the LT as they should be at that point.

The brief wrap-up lecture after the LT is completed would consist of leading a class discussion that consists of looking at the size and distance from the Sun of each terrestrial planet, including Earth's Moon. Then, based on these factors, predicting their geological and atmospheric conditions then verifying whether or not the predictions are accurate.

At the beginning of the next class period, the same questions asked before the LT should be asked as a review using the guidelines from the above discussion of classroom response/clicker questions.

LT vs. Lecture

Although some lecturing still occurs, before and after the LT, the difference between using LTs and a lecture-only approach is that the lectures before and after LT are much shorter and most of the instructional time is spent with students engaged in active and collaborative learning. They are working with a topic on their own before and after discussions rather than simply being told (lectured to) about it. Usually, the amount of time to give a comprehensive lecture on a topic, is about the same as the amount spent on the LT and the shorter lectures that is accompanied by. An excellent collection of LTs for introductory astronomy is found in the widely used workbook *Lecture-Tutorials for Introductory Astronomy*. (Prather et al., 2007) There is also now one for teaching the geosciences as well. (Kortz & Smay, 2010).

This recommended use of LTs (Prather et al., 2005, Slater, 2008: see Pasachoff et al., Prather & Brissenden, 2009, *Lecture Tutorials*) is very similar to the HSLs recommendations (Donovan & Bransford, 2005) and incorporates all four of the HPL environments. By their very nature, since they are designed to be done *by* students in *groups*, LTs are learner and community centered. Since they are geared toward using facts to teach concepts rather than just memorization of the facts, LTs are also knowledge centered. Finally, since assessments are recommended both prior to and shortly after their use, the pedagogy is assessment centered.

Mini-debates

It should be noted that a specific pedagogy that was *not* used in any of the tutorials written for this study was that of “mini-debates.” (Slater, 2010). This is where, usually at several points within a lecture tutorial, statements made by imaginary students “1 and 2” or “A and B,” related to the topic of the tutorial are included and students are instructed to read the statements and decided whether they agree with the statements or not. This is a way to encourage further discussion on the topic than that which may arise from group interaction required to answers the questions in tutorial. An added wrinkle that can cause the mini-debates to be even more though provoking is that sometimes the statements

made by the imaginary students are *both* right or *both* wrong. Although definitely not entirely new (Slater, 2010) or completely unique to Lecture-Tutorials for Introductory Astronomy (Prather et al., 2007), they are an integral feature of the tutorials in the manual. It was a conscious decision that the inclusion of this pedagogy in the tutorials in this study would occur at a later date if/when any of them were being modified to in format to be used in that manual, as a way to keep them somewhat distinct during their initial use and testing.

5.5 A Final Word

Andrew Fraknoi of Foothills College and the Astronomical Society of the Pacific recently published a summary of the observations he has made in what has now been over a decade of teaching introductory astronomy in an active and collaborative fashion. (Fraknoi, 2011) In his article, he makes seven important points that outline the elements of effective student –centered teaching;

- 1-Learning is not a spectator sport.
- 2-Collaboration beats competition.
- 3-Everything takes longer than you think.
- 4-Less is more.
- 5-Knew knowledge must be connected with prior conception.
- 6-Give and get immediate feedback.
- 7-Don't give walnuts to beggars with no teeth.

The first refers to the ineffectiveness of lectures. The second indicates that students should work together. The third and fourth together imply that the time taken by using various activities for instruction will limit the amount of content that can be covered. Five and six reiterate the importance of assessment both diagnostically to identify and work with misconceptions and formatively to monitor the learning the process. The final is a proverb that warns against trying to teach material that is at too high a level for the students, especially where mathematics is concerned.

All of these “*Seven Concepts for Effective Teaching*,” as he calls them (Fraknoi, 2011) are basically restatements of the HPL principles and environments and the HSLS recommendations and they have been observed to apply to the teaching of introductory astronomy.

The next chapter will outline the project of developing an introductory astronomy solar system unit based on the HPL principles and environments, (Bransford et al., 2000) the HSLS recommendations (Donovan & Bransford, 2005) and learner-centered teaching (Weimer, 2002) of astronomy. (Slater & Adams, 2003)

Chapter 6

Overview of the Learner-Centered Solar System Unit

6.1 Introduction

As stated in the abstract and chapter 1, the main goal of this project is to develop and assess the effectiveness of collaborative learning activities for introductory astronomy that focus on solar system topics and to also test the methods themselves through the implementation of these activities and their assessments. The intended end of the project is an entire solar system “unit” that is taught completely in a learner-centered fashion, by active and collaborative methods with very little lecturing.

6.2 The Course and Solar System Unit

The introductory astronomy course at Henry Ford Community College (HFCC) ASTR 131-Descriptive Astronomy is a one-semester, non-mathematical general survey of the entire range of astronomical topics that is meant to partially fulfill a general education science requirement. Below are the course description and structure, showing the four subjects or “units” into which it is divided, adapted from a course syllabus.

Description -3 Credit Hour; Prerequisite: None

Designed for general education, consists of a non-mathematical introduction to elements of the astronomical universe by means of lecture and planetarium demonstrations. Organized to interest the individual who is without scientific background but who desires to understand the major units of the universe and their interrelation. Three hours of lecture per week. (HFCC Course Catalog <http://www.hfcc.edu/programs/courses.asp>)

Inspection of the course description shows that a revision may be in order, replacing the term “lectures” with something similar to “in class activities and discussions.”

Structure-

SUBJECT

1-Celestial Motions
& Historical Astronomy

2-The Solar System

3- Light, Telescopes, the Sun & Stars

4-Galaxies, Cosmology
& Life in the Universe

The course meets twice per week for 80-minutes for 15 weeks. The 31 meetings, (including a final exam period in the 16th and final week of a semester) are divided approximately equally between the four subjects. The first subject has 8 class-periods of instruction (the first being an introduction and overview of the entire course), the second (the solar system, the focus of this project) and third 7 each and the fourth 6 periods. The remaining 4 class-periods are for the exams on each subject that usually occur one week after instruction on the topics are finished, the next subject beginning during the class period between the end of instruction on a subject and its exam.

The schedule for coverage of the main solar-system topics is as follows;

- 1-Solar System Overview;
size and scale, types of objects
- 2-Formation of the Solar System
- 3-Extra Solar Planets
- 4-Solar System Debris (Asteroids, comets and meteors)
- 5-Terrestrial Plants
- 6-Jovian Planets

The activities for which the development, use and assessment will be discussed in detail in Chapters 8-13 are, in the order that they are assigned;

1-The HFCC Solar System Walk

2-Comparative Planetology

3-Formation of the Solar System

4-Extra-Solar Planets

5-Comets

6-Surface Conditions of Terrestrial Planets

1-Planetary Geology

2-Planetary Atmospheres

The next chapter is a discussion of a “pilot research project” designed and undertaken as a ”test-run” of the methodology to be used to in evaluating the materials developed for the main part of this project, an active and collaborative, learner-centered, solar system unit.

Chapter 7

Pilot Research Project: Using the Star Properties Concept Inventory to Compare Instruction with Lecture-Tutorials to Traditional Lectures

7.1 Introduction

The goals of the main study in this project are to develop and assess the effectiveness of active and collaborative instructional materials on solar system topics and to then assess the methods of learner-centered teaching themselves. This will be done by comparing both the materials and the teaching methods in which they will be used with traditional lectures on the same topics. Developing both the instructional materials and the multiple-choice assessment questions are part of the project.

A logical pilot-project to test the viability of this idea is to use learner-centered instructional materials that are already in existence on other topics and test them with an already existing and established assessment instrument. Based on the number of Lecture-Tutorials (LTs) available on the subjects of light, the Sun and stars (Prather et al., 2007) and the existence of an already established concept inventory, the *Star Properties Concept Inventory* (SPCI) (Bailey, 2008) the third unit in HFCC's introductory astronomy course, telescopes, light, the Sun and stars, is an obvious choice.

7.2 The SPCI

The *Star Properties Concept Inventory* (SPCI) is one of the first instruments that has been developed and made available to assess student gains for an entire major section or "unit" of a traditional introductory astronomy course. This is in contrast to instruments for an entire course, such as the *Astronomy Diagnostic Test*, ADT (Deming, 2002, Hufnagel, 2002, Zeilik, 2003), or the *Lunar Phases Concept Inventory*, LPCI (Lindell, <http://people.rit.edu/svfsp/perc2002/Lindell.pdf>) that is for a single subject. One of the intended uses of the SPCI is for comparison of the effectiveness of different instructional methods. (Bailey, 2008) In this pilot-study the SPCI was used as a pretest and posttest to compare gains in sections taught by active and collaborative student-centered instruction

using Lecture-Tutorials to gains in sections taught with traditional instructor-centered lectures.

7.3 The “Stars” Unit

By the Fall semester of 2008, the coverage of topics in the third major unit in HFCC’s introductory astronomy course, on telescopes, light, the Sun and stars, had evolved into largely centering on LTs from “Lecture-Tutorials for Introductory Astronomy,” (Prather et al., 2007). The following eleven tutorials were used over the course of the seven class periods devoted to coverage of these topics;

Electromagnetic (EM) Spectrum of Light

Telescopes and Earth’s Atmosphere

Luminosity, Temperature and Size

Blackbody Radiation

Types and Spectra

Apparent and Absolute Magnitudes of Stars

The Parsec

Parallax and Distance

H-R Diagram

Star Formation and Lifetimes

Stellar Evolution.

As discussed in Chapter 5 and indicated by their name, Lecture-Tutorials (LTs) are *not* designed to completely replace lectures. Rather, they are meant, after a short introductory lecture on a topic, for students to spend 15 to 20 minutes, or about 5 minutes per page, exploring concepts through guided-inquiry in an active and collaborative fashion. A short debriefing meant to help students pull together the important ideas from the activity should then follow the LTs. (Bailey, 2005: see Pasachoff & Percy, Prather et al., 2005, Slater, 2008: see Pasachoff et al., Prather & Brissenden, 2009, *Lecture Tutorials*)

7.4 Method

During the Fall 2008 semester at HFCC, two sections of ASTR 131 were taught using the above-listed LTs and two sections were taught by traditional instructor-centered lectures. All four sections were given the SPCI-Version 3.0 as a pretest shortly before the beginning of the unit and as a posttest a week after the exam on the topics.

After the individual topics relevant to the specific items on the SPCI had been covered, all four sections were given the SPCI content questions as classroom response/“clicker” (Duncan, 2007) review questions. This was done at the beginning of the next class meeting after coverage of the relevant material. Thus serving as a formative, or embedded, assessment. (Bransford et al., 2000, Wilson & Sloan, 2000) Formative assessment through classroom response is line with the recommended use of LTs. (Prather et al., 2005, Prather & Brissenden, 2009, *Lecture Tutorials*) Note that using the SPCI questions in this way was done with the permission of the author (Bailey, 2008),

7.5 Results

SPCI	N-Number of students Taking assessment	Average Score of N students out of 23 items on the assessment	Average percentage Score of N students taking the assessment	Standard Error of N students taking the assessment	Normalized Gain above pretest average
Pretest	89	6.2	26.9 %	± 1.1	
Posttest (lecture)	47	13.1	57 %	± 2.7	0.41
Posttest (LTs)	41	14.6	63 %	± 3.4	0.50

Table 7.5.1 Fall 2008 SPCI Pretest and Posttest results for sections taught by lecture and LTs.

As can be seen in Table 7.5.1 the standard errors of the average posttest scores 57 ± 2.7 and 63 ± 3.4 , for the lecture and tutorial groups respectively, do overlap, but not by much. No overlap at all is the goal, but this small overlap is encouraging enough to consider the results of the pilot study cause to continue on with the plans for the main study.

Fig. 7.5.1 shows the number of students scoring from 0-23 on the pretest and in both groups on the posttest. Note that the peak of the distribution of scores on the posttest by students having done the tutorials (yellow) shows a greater gain from the distribution of pretest scores (blue) than the scores of those that received lectures (red).

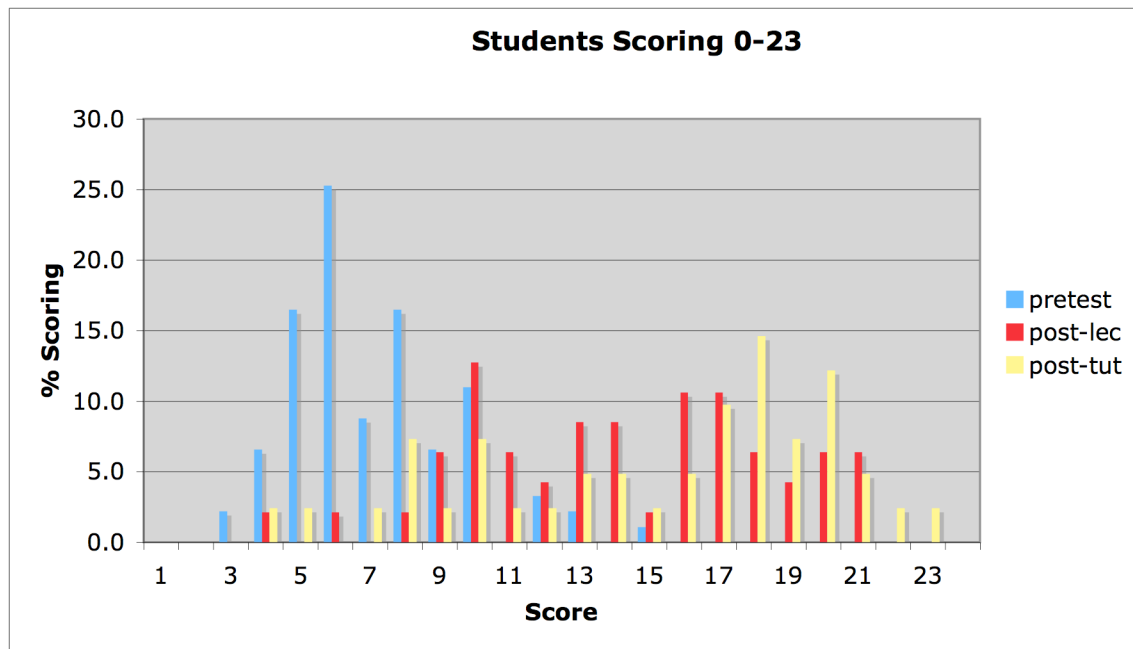


Figure 7.5.1. Fall 2008; percentage of students scoring 0-23 on the pretest (blue), the posttest in lecture sections (red) and in tutorial sections (yellow).

Fig. 7.5.2 shows the percent of correct posttest responses by both groups for each SPCI item and Fig. 7.5.3 shows the normalized gains, $g = (\text{post. \%} - \text{pre \%}) / (100\% - \text{pre \%}) = \text{actual gain} / \text{possible gain}$, (Hake, 1998) for the individual items by both groups. Inspection of the figures shows LT sections with higher gains on 11 of the 23 items, especially items 2, 6, 12, 13 and 15 and the lecture sections with higher gains on 5 items. The two groups had similar gains on 7 items.

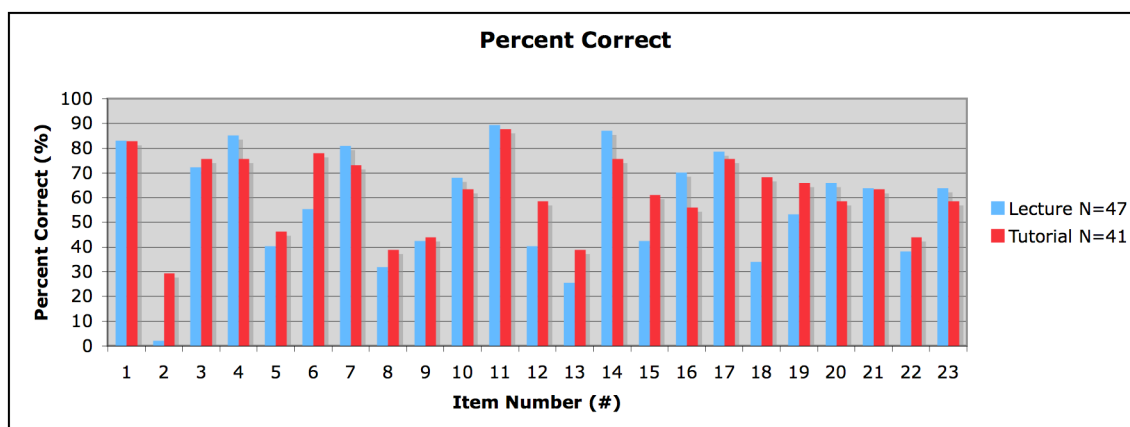


Figure 7.5.2 Fall 2008; percent correct on each item on posttest in lecture sections (blue) and tutorial sections (red).

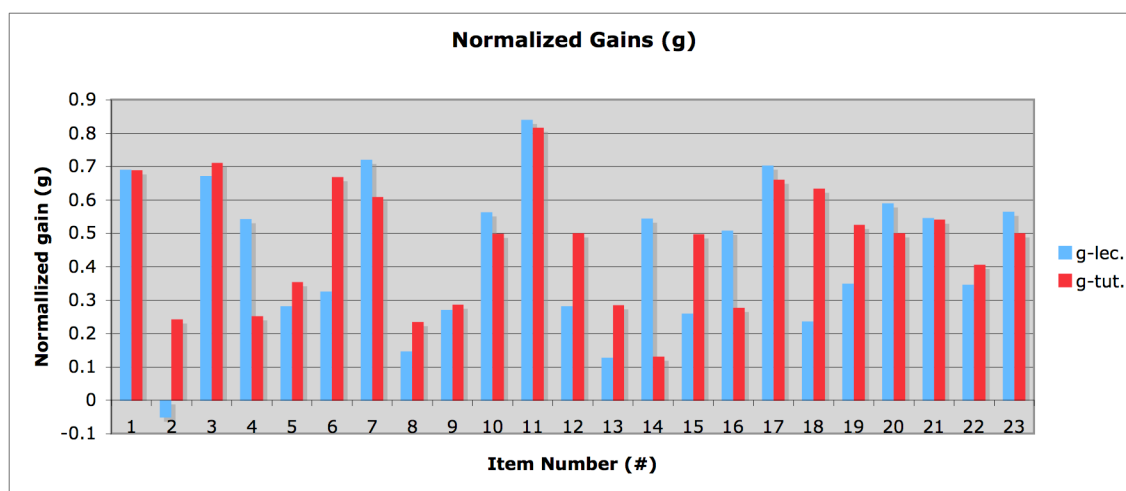


Figure 7.5.3 Fall 2008; normalized gains, g , for each item on posttest in lecture sections (blue) and tutorial sections (red).

Three of the five items on which the lecture sections out-performed the LT sections were about star-birth, energy being produced in the core, and mass determining the final fate of a star. These are subjects that are not covered in the LTs, so both groups received lectures about them. Although both groups performed well on it, the lecture sections had higher gains on a simple question relating star color and temperature and a more involved one on size and brightness of different color stars. Both of these questions are on topics that were covered in LTs and also can be visualized with the Hertzsprung-Russel (HR)

Diagram, so it is surprising that the lecture sections did better on them. However, the tutorial sections did better on three other questions on related topics, suggesting that they had benefited from actually working with HR diagrams in several LTs. The LT sections also out-performed the lecture sections on two questions about how the mass and lifetime of a star are related, including one that stresses that the relationship is not linear, which also was the subject of one of the LTs. For protection of the instrument, items from the SPCI are not shown and only referred to in a general fashion. (Bailey, 2008)

It is difficult to judge why one group or another did better on a specific item and it cannot be expected that individual questions in samples of these sizes would show statistically significant results. However, comparing the averages of two groups with standard errors and the number of questions on which one group out performed the other is more general and therefore likely more valid. Based on this pilot study these will be the statistical standard to which the main study will be held. (Gonzalez, 2010)

7.6 The Use of Classroom Response Questions/ “Clickers”

Prior to the study, in the Winter 2008 semester, the SPCI had been given to three sections of ASTR-131 taught by two different instructors at HFCC. The sections were taught largely with the above-listed tutorials, but the SPCI questions had *not* been used as classroom response/ “clicker” questions. The results from that semester are in Table 7.6.1. The gain was comparable to that in a study by the author of the SPCI (Bailey, 2008) using the same version of the instrument (3.0) also seen in Table 7.6.1. Since the purpose of this pilot-study is to test the methodology of the larger scale main project described in Chapter 6 and reported on in Chapters 8-12, the similar results to the original study are reassuring.

SPCI	Pretest	Posttest	Normalized gain
Winter 2008	N=61 students Average score=5.7/23 Percentage =24.8±1.4 %	N=69 students Average score=10.5/23 Percentage =45.7±2.4 %	g=0.27
Winter 2009	N=37 students Average score=6/23 Percentage=26%	N=45 students Average score=11.5/23 Percentage=50%	g=0.32
Original Study (Bailey, 2008)	Percentage=31%	Percentage=51%	g=0.29

Table 7.6.1 Comparison of SPCI Pretest and Posttest results for sections taught with LTs, but *not* clickers.

Comparison with results shown in Table 7.5.1 that during the Fall 2008 study, the pretest scores were similar to those in Winter 2008 but the posttest scores in Fall 2008 and gains were *higher* than in Winter 2008, for *both* groups, both the sections taught with LTs *and* those taught by lecture. This suggests that either using the SPCI items as clicker-questions was too much “teaching to the test” or that this was an example the well-documented effectiveness of using “clickers” in the classroom. (Duncan, 2006, Lasry et al., 2008, Mazur 2009) This question prompted a follow up to the study in Winter 2009 in which two sections, taught in similar fashion to Winter 2008, *with* LTs but *without* the SPCI items as clicker questions. As seen in Table 7.6.1, results were similar to Winter 2008, again, also in which clickers were *not* used, and also similar to the initial study by the instrument author. (Bailey, 2008)

7.7 Teaching to the Test, the Hawthorn Effect and Instructor Bias

Note that the precautions, taken to minimize *instructor bias*, the *Hawthorn Effect* and *teaching to the test*, to be described below, were used during all parts of the main study described in Chapters 8-13.

The author of the SPCI (Bailey, 2008), who again *had* given permission to use the items as clicker questions, was of the opinion that based on time having elapsed before the posttest was administered, using the SPCI items in this fashion probably did not amount “*teaching to the test*” (Bailey, 2008) and advocates of teaching with LTs maintain that gains are *not* just a result of repeated exposure to the assessment questions. (Prather et al., 2005) Finally, the fact remains that although both the LT and lecture sections taught with clickers in Fall 2008 outperformed the sections not taught with clickers, the sections also taught with LTs did outperform those taught by lectures only.

The *Hawthorn Effect* (Hake, 1998, from Slavin, 1992) occurs when special attention is given to a research test group that could affect the results of the study. Teaching with LTs requires that the instructor circulate around the room and be available to answer questions and participate in discussions (Prather et al., 2005, Prather & Brissenden, 2009, *Lecture Tutorials*) so part of the advantage of the pedagogy *is* giving students more individualized attention. (Hake 1998)

The more assessments and different instructional methods are used, the more routine and common-place they become to both the students and the instructor, so as a rule the Hawthorn Effect should diminish with time. (Hake 1998) The coverage of stars was in the second half of the course by which time students were used to both LTs and assessments. Also, both instructors were experienced in teaching by these methods.

Since the sections participating in the study were taught by two different instructors, each taught sections by lecture and sections using LTs. So students that received lectures were not all hearing them from the same instructor nor did all the students doing LTs have the same instructor. Also, the concepts assessed were covered in all sections regardless of

instructional method or instructor. This was by design to minimize any, what could be called “*Instructor bias*,” in assessment results.

Again, these precautions, taken to minimize *instructor bias*, the *Hawthorn Effect* and *teaching to the test* were used during all parts of the main study.

7.8 A Question of Ethics

A question brought up by the eventual co-author of the published article on this pilot study (LoPresto & Murrell, 2009) was whether it was ethical to teach different groups of students with different methods if it was known that one method was better than another.

A very important question to answer and the truth at the time of this pilot study was, although it was expected that groups doing LTs would experience higher gains than those that did not, there had not yet been a definite study showing this would be the case. The format of this study, direct comparison with the same assessment instrument of students who did LTs with those who did not, was similar to a previous study (Alexander, 2004) that *did not* show an advantage in the use of LTs. Another study that did (Prather et al., 2004) was actually comparing student gains after lectures to gains after tutorials of the *same group* of students, assessed first after lecture, then after the LT.

For the solar system activities of the main study for which this study on stars was a pilot, a large part of the reason for focusing on solar system activities was, as mentioned in the rationale for the study in the abstract, that compared to other areas of astronomy there was a shortage of them. So there really were very few, if any, solar system activities for which there was definitive data on whether or not doing the activities would result in student gains superior to hearing lectures on the subject.

7.9 Conclusion of Pilot Project

As mentioned above, a study similar to this one done with the Astronomy Diagnostic Test, ADT, over an entire course did not show much difference between gains in sections using LTs versus sections receiving traditional lectures. (Alexander, 2004) However posttest scores of the group that did the LTs in this study did experience higher gains. This is what was expected based on previous research showing the effectiveness of LTs, (Prather et al., 2004).

Results of this pilot study also showed increased gains as a result of the use of “clickers” of formative assessments. This suggests that instruction with a combination of LTs and formative assessments with classroom-response systems are an effective combination. Instruction of this type is exactly in line with HPL pedagogy (Bransford et al., 2000) and the HSLS guidelines (Donovan & Bransford, 2005) and is part of what will be tested in the main study on solar system topics. Reports on the development and results of this study begin in the following chapter.

The main purpose of this pilot-study was to test the methodology for the main study. Results of this study (LoPresto & Murrell, 2009) show that similar procedures with materials developed for that study should be viable.

Chapter 8

A Solar-System Walk

8.1 Introduction

HFCC's active and collaborative solar system unit begins with students being sent on a walk through a scale model of the solar system. This is an attempt to instill an appreciation of the relative scales of the sizes of the objects compared to the immense distances between them. This is certainly not a new idea, a good number of such models exist including one on the National Mall in Washington D. C. , starting at the Smithsonian Air & Space museum. (Bennett, http://www.jeffreybennett.com/model_solar_systems.html) A pioneering model and inspiration for our own is on the campus of the University of Colorado in Boulder, (Bennett et al., 1991) and there are others as well. What is unique here is the assessment of the effectiveness of a walk through such a model when it is compared to lectures on the subject of size and scale. (LoPresto et al., 2010)

8.2 A Size and Scale Lecture-Demonstration

For many years, before the model at Henry Ford Community College was built, introductory astronomy students participated in an interactive lecture/demonstration on solar system sizes and distances. Weather permitting, it took place on a sidewalk outside the Science Building or if not, in long basement hallway in the Science Building. A softball was used for the Sun and after students were asked to guess the sizes of different planets in comparison to the softball, larger marbles for Jupiter and Saturn, smaller ones for Uranus and Neptune and small ball bearings comparable in size to the heads of pins, map-tacks or starter-earrings for the Terrestrial planets, were revealed.

Volunteers were then asked to place objects at their estimates of appropriate relative distances from the softball to begin construction of a solar system scale model. As may be expected from most pictures and models that people see, students usually began with gross underestimates of distances, but soon caught on and the inner solar system began to

take shape with the tiny pinhead sized Terrestrial planets all within about 50 feet of the softball-sun (1 AU=about 30 feet).

The distances to the outer, Jovian, Planets and Pluto were usually only imagined, often visualized in terms of football fields. Jupiter, at about 5AU, a large marble half a football field from the softball-sun (50 yards=150 feet), another large marble, Saturn, at about 10 AU, a whole football field away, then small-marbles, Uranus and Neptune, at about 20 and 30 AU, each another additional football field beyond Saturn. Pluto at about 40 AU, a tiny little piece of copper-shot, a total of about four football fields, more than half a mile, from the softball.

8.3 The Model

After a number of years of hearing students express amazement at how tiny the objects seemed compared to immense distances between them, with virtually nothing in between, the decision was made to design and build a more permanent scale model of the solar system on campus. Figure 8.3.1 shows the positions of each object in the model on campus. Figure 8.3.2 is a close up of the Sun's display case. Like the Sun's, each display case in the model shows a picture of the object, some information about it and a map of the model to help users find the next object.

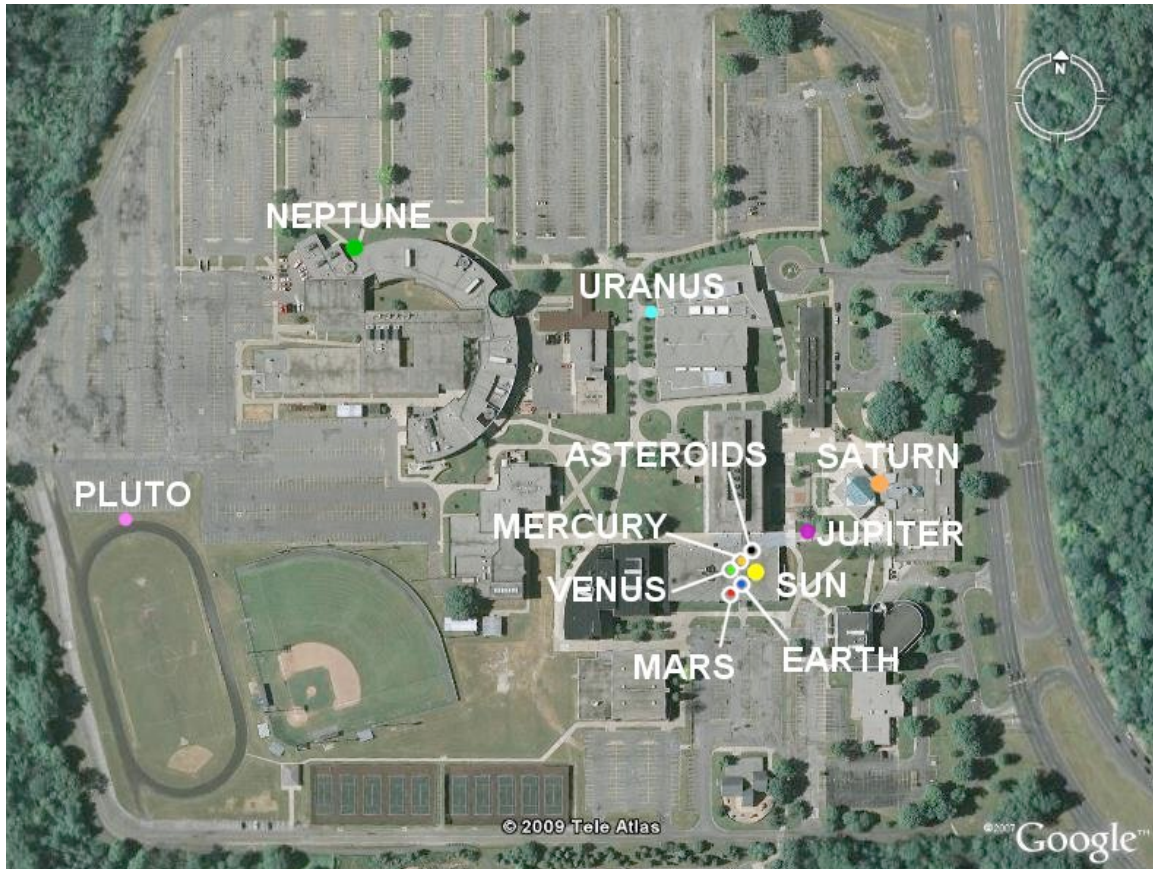


Figure 8.3.1 Overhead view of the positions of objects on campus in the *HFCC Solar System Model*. One unique feature about the HFCC model is that the planets are depicted in different locations along their orbits, not all in a straight line as in many models of this type. (Bailey, 2009) It is certainly possible that having the planets in a straight line may make the relationship between the size of the objects and the distances between them clearer, but this is also much less realistic, in that such an alignment rarely, if ever, occurs.

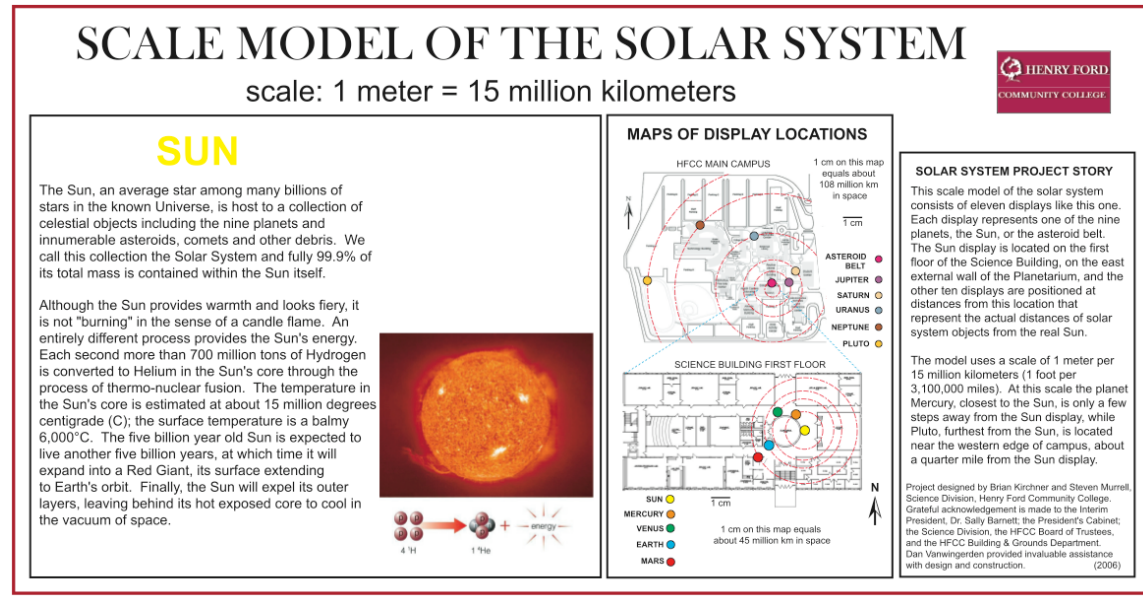


Figure 8.3.2 Information in the Sun's display case in the *HFCC Solar System Model*.

As can be seen in Fig. 8.3.3, the Sun is still about softball size, so the scale of the model is still 1 AU=30ft. This makes the speed of light about 30ft/8min, which is only about three-fourths of an inch per second.



Figure 8.3.3 Field-trip visitors inspecting the *HFCC Solar System Model's* Sun display.

8.4 Assessing the Walk

Initially, students were simply asked to turn in a paragraph write-up of any general impressions they had of the model. Many of them indicated that they were impressed or even amazed by how large the distances were compared to the objects, which was exactly the goal of the exercise. This student reaction was considered a validation of the purpose of the model, however, in an attempt to have more quantitative evidence of the model's usefulness, an assessment was implemented in the form of the following six multiple-choice questions;

Solar System Walk Questions

1. If the Sun was the size of a softball, the solar systems largest planets would be about the size of a
 - a. head of a pin
 - b. big marble.
 - c. golf ball.
 - d. baseball.

2. If the Sun was the size of a softball, Earth would be about the size of a
 - a. head of a pin
 - b. big marble.
 - c. golf ball.
 - d. baseball.

3. If the Sun was the size of softball, about how far from the softball should the object representing Earth be?
 - a. 3 feet
 - b. 30 feet
 - c. 300 feet
 - d. 3 miles

4. If the Sun was the size of a softball, about how far from the softball should the object representing Jupiter be?
 - a. 15 feet
 - b. 150 feet
 - c. 1500 feet, on the other side of campus
 - d. off campus

5. If the Sun was the size of a softball, about how far from the softball should the object representing Pluto be?
 - a. 15 feet
 - b. 150 feet
 - c. 1500 feet, on the other side of campus
 - d. off campus

6. If the Sun was the size of a softball, about how far from the softball should the object representing the nearest star to our sun be?
 - a. on the other side of campus
 - b. on the other side of town, a few miles
 - c. on the other side of the state, a few hundred miles
 - d. on the other side of the country, a few thousand miles.

The questions were administered to four sections of introductory astronomy (two each taught by two different instructors) of about thirty students each as a pretest in the Fall 2008 semester. Then two sections (one by *each* instructor to minimize instructor bias) were given the lecture/demonstration described above and two sections (again one by each instructor) were assigned to walk through the model with a short, guided tutorial in hand. The tutorial, *The HFCC Solar System Walk*, is found in *Appendix 8.1*. The lecture/demonstration usually took 20 to 25 minutes of classroom time, while the walk, done on the student's own time, was reported to take 30 to 45 minutes.

8.5 Results

The majority of the 44 students that submitted the tutorial responded correctly to most of its questions. At the end of coverage of the solar system the six questions were again given to all sections as a posttest. Results are shown in Table 8.5.1 and Figs. 8.5.1 and 8.5.2

Question	% Correct	% Correct	% Correct	Normalized gain -g	Normalized gain -g
Item #	Pretest N=100 students	Posttest (lecture) N=40 students	Posttest (walk) N=44 students	g-(lecture) from pretest	g-(walk) from pretest
1	54	52	68	-0.043	0.304
2	67	78	81	0.333	0.424
3	40	42	54	0.033	0.233
4	29	32	61	0.042	0.451
5	27	15	47	-0.164	0.274
6	14	35	34	0.244	0.233
Average	38.5	42.3	57.5	0.074	0.32
Standard Error	±7.2	±8.0	±6.1	±0.075	±0.039

Table 8.5.1 Percentage of correct responses to questions on pretest and posttests and normalized gains, Fall 2008. Normalized gain, $g = (\text{post. \%} - \text{pre \%}) / (100\% - \text{pre}\%) = \text{actual gain} / \text{possible gain}$. (Hake, 1998)

Inspection of Table 8.51 shows that sections that went on the walk had greater gains on four of the six items and there were comparable gains on two. The sections that went on the walk also had a higher average posttest score than those that did not and note that the standard errors *do not* overlap. This was also true of the normalized gains and the their averages and standard errors.

Sections that did not go on the walk, but received the previously mentioned lecture/demonstration of size and scale, scored much lower on item 5 about the distance to from the Sun to Pluto on the model. This suggests that actually having the walk the distance instilled a much greater appreciation of how far away Pluto really is.

The groups were comparable on the last question, about where the next closest star and its solar system should be relative to the model. This is of course not something actually seen in the walk through model. Students that went on the walk were asked to estimate this in a question on the tutorial (see *Appendix 8.1*) while students in the lecture sections were verbally asked to do so and eventually told the answer.

HFCC students are told, with permission of the creators (Rosenthal et al. 2007), that a model located at Paradise Community College, near Phoenix, Arizona, is “the next solar system over” from the HFCC model in Dearborn, Michigan near Detroit and reminded that between Arizona and Michigan there would be nothing but nearly empty interstellar space.

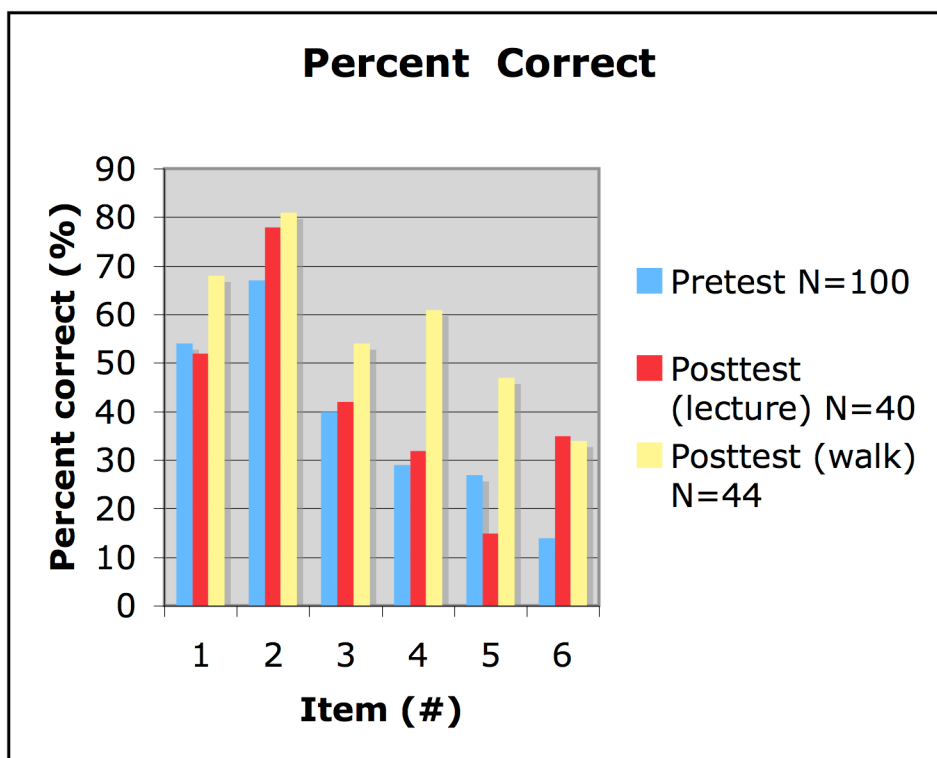


Figure 8.5.1 Plot of percentages of correct responses to each item on the pretest (blue), posttest for students who received lecture (red) and students who went on the solar system walk (yellow), Fall 2008.

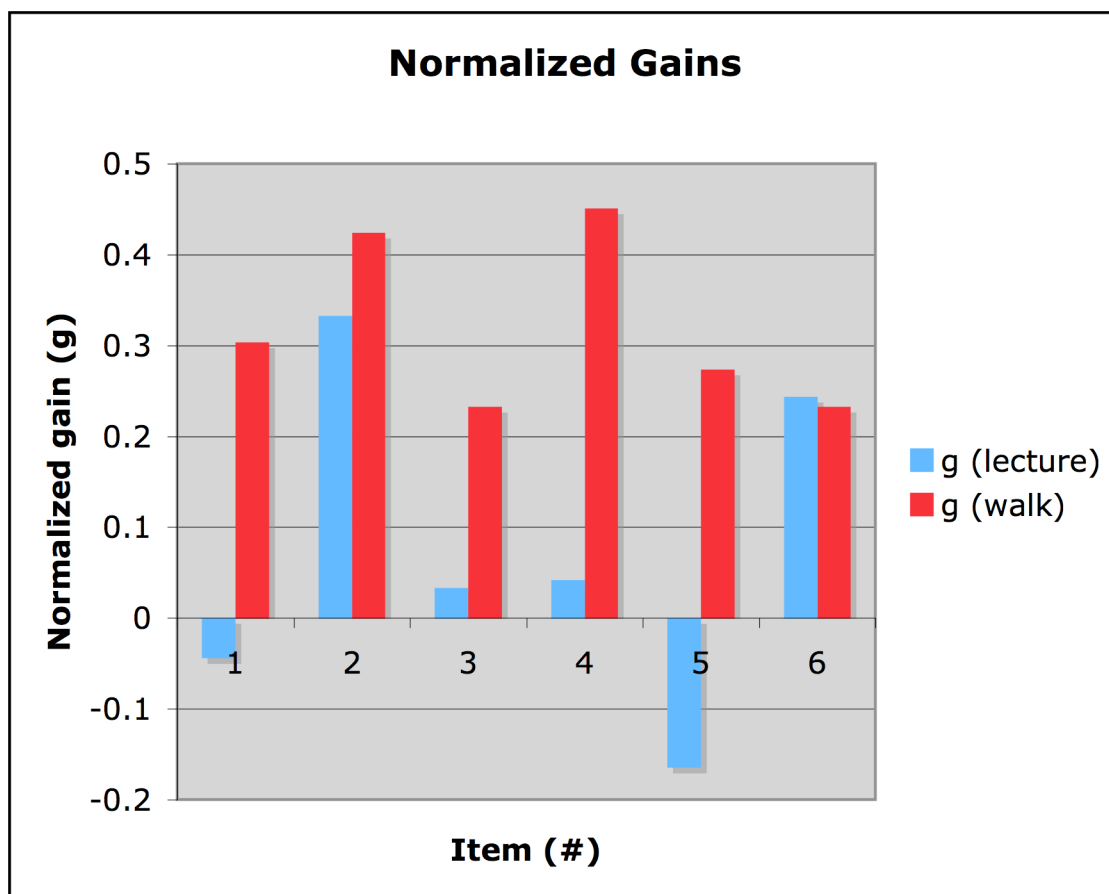


Figure 8.5.2 Plot of normalized gains on each item for the lecture sections (blue), and the students who went on the solar system walk (red), Fall 2008.

Table 8.5.2 and Figure 8.5.3 show posttest results for students assigned the walk in the Fall 2009 semester. Items 1-5, relating to material covered by the tutorial during the walk and actually seen during the walk, show a very high percentage of correct responses, even higher than during the Fall 2008 semester. Item 6, again about something not actually seen in the model, was in fact not covered at all that semester. This was due to the fact that during the Fall 2009 semester, Pluto was removed from the model, due to parking-lot construction so students could not visit it. Most then did not complete the tutorial beyond question 8 about the Jovian planets and as a result, the final question on the tutorial (10) where they are asked to speculate about where the nearest star would be on the scale of the model was not completed and consequently no questions, other than two curious students one day after class, were asked about it and it never got formally covered.

Questions	% Correct
Item #	Posttest (walk) N=81
1	67
2	69
3	70
4	72
5	72
Average	70±0.95

Table 8.5.2 Percentage of correct responses to questions on posttest only for students that were assigned the solar system walk during the Fall 2009 semester.

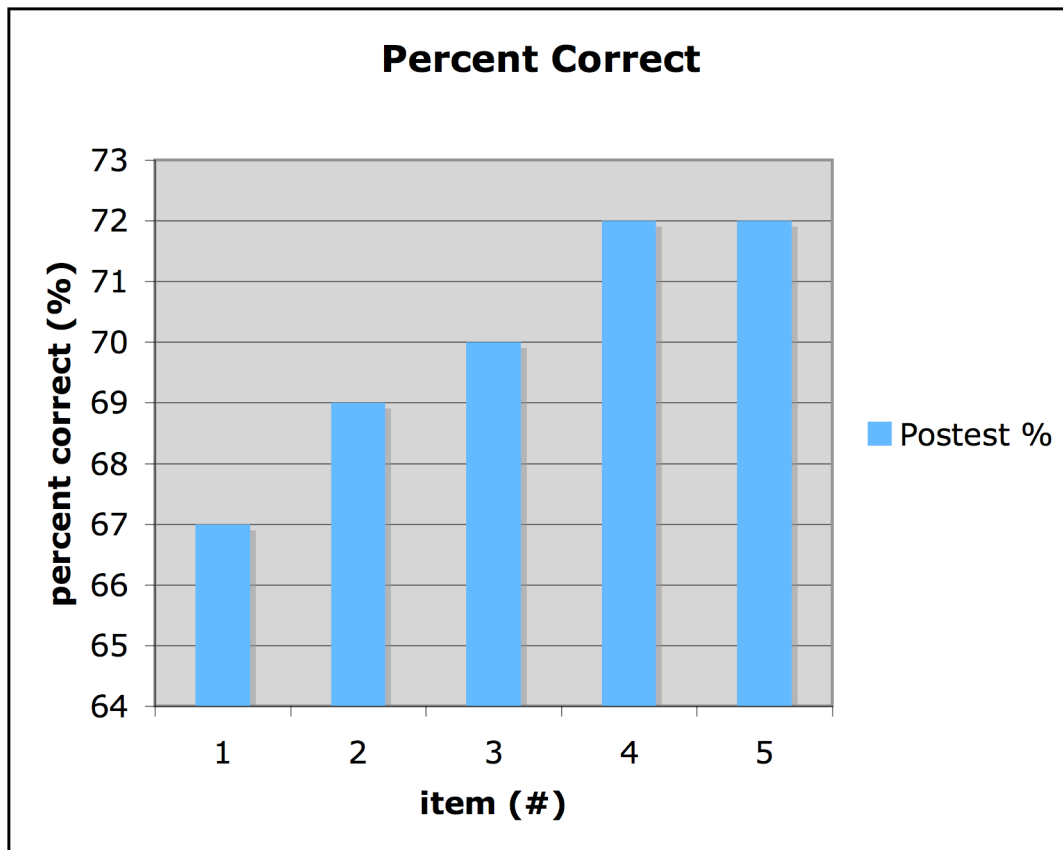


Figure 8.5.3 Plot of percentages of correct responses to each item on the posttest only (blue), for students who went on the solar system walk in Fall 2009.

8.6 HPL Pedagogy

The fact that the students did this activity without the presence of instructors *does not* automatically make it learner centered. The students were however expected to find their own way through the “solar system” making use of maps made available in the display cases once they were told where to start and the process of finding each “planet” and answering questions (see appendix 8.1) designed to help them visualize the sizes of objects in the solar system compared to the distances between them on the same scale rather than hearing a lecture or even seeing a demonstration on the subject.

Although the activity could be done alone, students were encouraged to take the walk in groups making it potentially community centered. Although the distances in the worksheet and the assessment *are* given in terms of numbers of feet that *could* be memorized, successful comparison of the distances to sizes that are given in terms of familiar objects on the assessment suggests that the facts are actually being used and that more than just memorization is indeed going on. This makes the activity knowledge centered.

Ideal use of a solar system model, when it is not being tested for its effectiveness, would be in the fashion of the HPLS recommendations for effective science instruction (Donovan & Bransford, 2005) by posing assessment question both prior to assigning the walk and after it has been done. Questions prior to the walk need not be only the multiple-choice assessment presented here. Students could be given the worksheet they will take on the walk and asked to use it to make predictions that they can test when they actually go on the walk. Assessment after the walk should be done formatively to determine if any additional discussion of solar systems scales is necessary. These ideas incorporate the fourth HPL-environment which would make the exercise assessment-centered. (Bransford et al., 2000)

This is exactly what was done during the Fall 2010 semester. This also included, in attempts to minimize any Hawthorne effect (Hake, 1998, from Slavin, 1992) or instructor bias, *none* of the sections participating in the study in Fall 2010 being taught by the author.

The results, shown in Table 8.6.1 and Figures 8.6.1 and 8.6.2 (note that as in Fall 2009 only items 1-5 of the assessment were used), were even more impressive than in Fall 2008, showing an even larger disparity in the posttest results between students that participated in the walk and did not. Students that went on the walk had higher scores and gains on all five questions and the averages without any overlap in standard errors.

Question	% Correct	% Correct	% Correct	g	g
Item #	Pretest N=116	Posttest (lecture) N=36	Posttest (walk) N=65	(lecture)	(walk)
1	51.7	52.8	89.2	0.022	0.78
2	58.6	50.0	89.2	-0.21	0.74
3	36.2	50.0	83.1	0.22	0.734
4	23.3	25.0	76.9	0.022	0.70
5	24.1	13.9	78.5	-0.14	0.72
Average	38.8	38.3	83.4	-0.017	0.732
Standard Error	±7.2	±7.9	±2.6	±0.073	±0.0132

Table 8.6.1-Percentage of correct responses to questions on Pretest and Posttests and normalized gains, Fall 2010. Normalized gain, $g = (\text{post. \%} - \text{pre \%}) / (100\% - \text{pre}\%) = \text{actual gain} / \text{possible gain}$. (Hake, 1998)

These rather dramatic results are most likely due to the above-mentioned implementation of the HLSTL recommendations described, also above, as its “ideal use” of the solar system walk. The students in sections that were being assigned to go on the walk were given the tutorial during the class period it was assigned and asked to predict the answers, making it a diagnostic assessment. They were then instructed to, if necessary, correct their predictions when they actually went on the walk. The class period that the tutorial on the walk was due, a week after it was assigned, students were instructed to discuss their results with other students in the class (other than those with whom they had gone on the walk) and resolve discrepancies in their answers before handing it in. This was use of the tutorial as a formative assessment. The students that did not go on the walk received a lecture only, so they did not participate in diagnostic or formative assessment. So, to reiterate, this means that the comparisons in Table 8.6.1, above, and Figs. 8.6.1 and 8.6.2 below, are between students in groups that were taught with full HPL pedagogy to those that received lecture only.

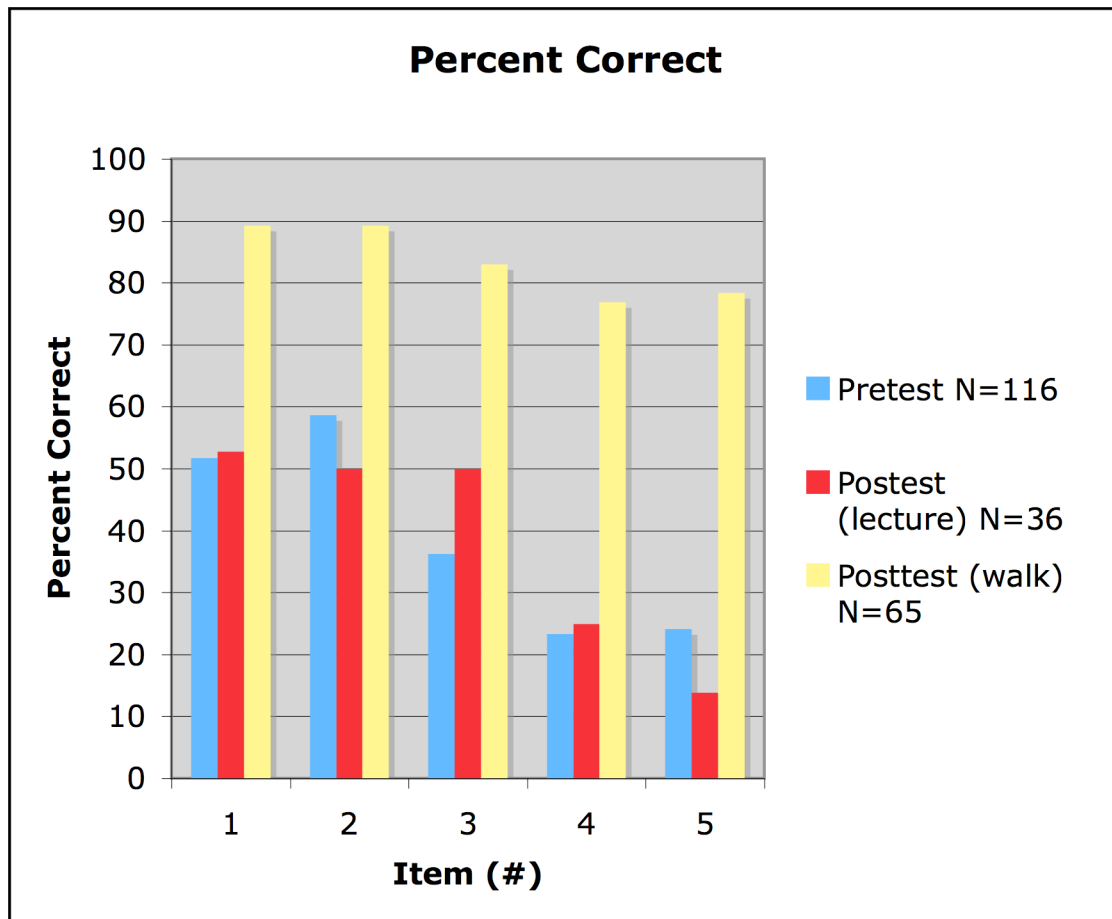


Figure 8.6.1 Plot of percentages of correct responses to each item on the pretest (blue), posttest for students who received lecture (red) and students who went on the solar system walk (yellow), Fall 2010.

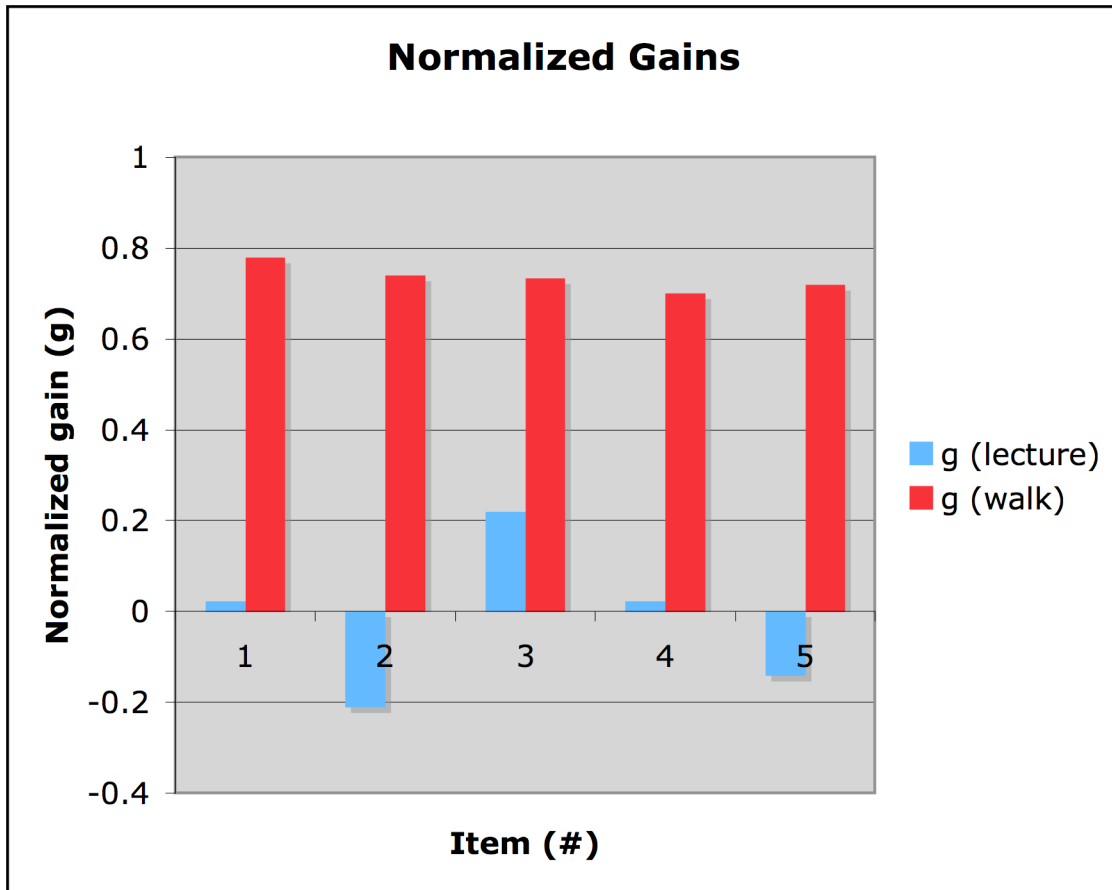


Figure 8.6.2 Plot of normalized gains on each item for the lecture sections (blue), and the students who went on the solar system walk (red), Fall 2010.

It should be noted that a published article (LoPresto et al., 2010) on the study discussed in the chapter was selected for a list of “Good Reading from Other Sources on Astronomy Education and Outreach (Published in 2010)” in the *Astronomy Education Review* (AER), http://aer.aas.org/resource/1/aerscz/v10/i1/p010301_sl. (Fraknoi, 2011)

Chapter 9

A Comparative Planetology Activity

9.1 Introduction

Immediately after students are assigned the *Solar System Walk* featured in the previous chapter, in-class coverage of solar system topics begins. The following activity, that is what is done first, is designed to establish the two planet-types; the Earth-like or *Terrestrial* planets and the Jupiter-like or *Jovian* planets through conclusions drawn by students after a guided analysis of planetary data. (LoPresto & Murrell, 2010)

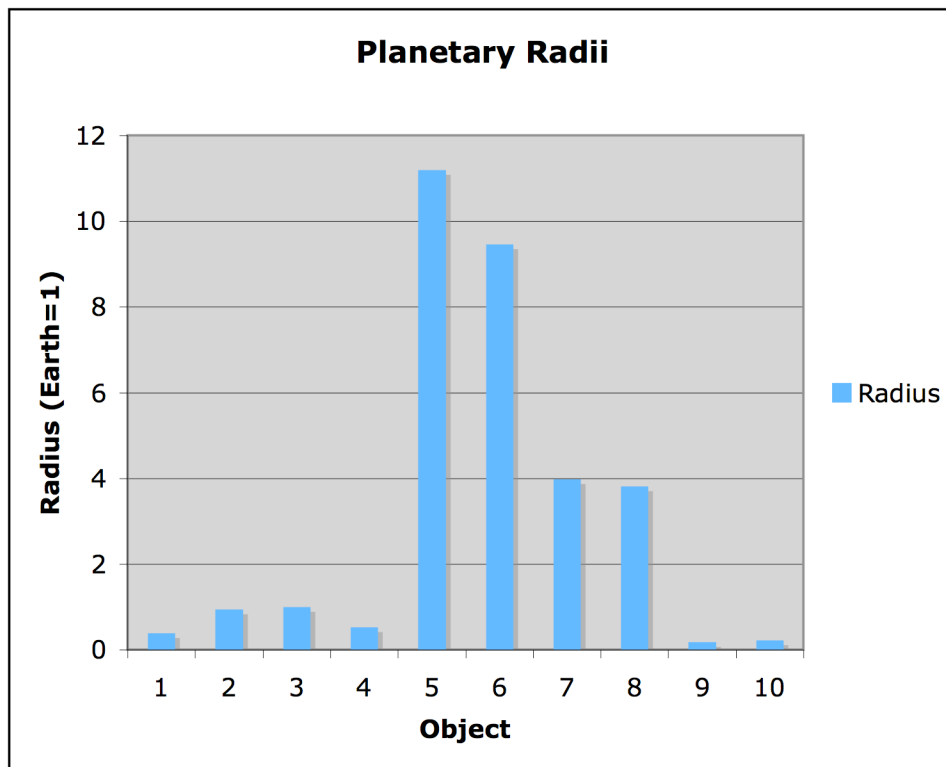
9.2 Analyzing the Data

Prior to any coverage, including any reading assignments on the solar system, different groups of several students each are assigned one category of planetary data and asked to plot a histogram of the data then transfer it to a chalk or whiteboard in the classroom. In our relatively small classes at HFCC (30 student per section maximum), one group is assigned each of the categories in Table 9.2.1.

	Object	Radius	Mass	Density	Orbital Radius	Orbital Period	Rotation Period	Number of
		Earth=1	Earth=1	Water=1	AU	years	Earth=1	Moons
1	Mercury	0.382	0.055	5.43	0.387	0.2409	58.6	0
2	Venus	0.949	0.815	5.25	0.723	0.6152	-243	0
3	Earth	1	1	5.52	1	1	0.9973	1
4	Mars	0.533	0.107	3.93	1.524	1.881	1.026	2
5	Jupiter	11.19	317.9	1.33	5.203	11.86	0.41	21
6	Saturn	9.46	95.18	0.7	9.539	29.42	0.44	63
7	Uranus	3.98	14.54	1.32	19.19	84.01	-0.72	27
8	Neptune	3.81	17.13	1.64	30.06	164.8	0.67	13
9	Pluto	0.181	0.0022	2.05	39.48	248	-6.39	3
10	Eris	0.22	0.0028	2.3	67.67	557	15.8	1

Table 9.2.1 Planetary Data-Note that by this time in the course, students are already familiar with “Earth=1” units for comparing planetary data, including the Astronomical Unit. (Data Source, Bennett et al., 2009)

Students then study the histograms guided by a short tutorial, *Comparative Planetology* that is found in *Appendix 9.1*. Comparison of histograms of planetary radii, mass and density in Figure 1 show Mercury, Venus, Earth and Mars “together” every time and opposite Jupiter, Saturn, Uranus and Neptune, that are also always together. Pluto and Eris change from being with the smaller, less massive, more dense group of Earth is a part of, to the other group with Jupiter. Comparison of planetary masses often suggests to students the groupings heavy, middle and lightweight planets, but when comparing radii and density they see Uranus and Neptune as belonging grouped with Jupiter and Saturn.



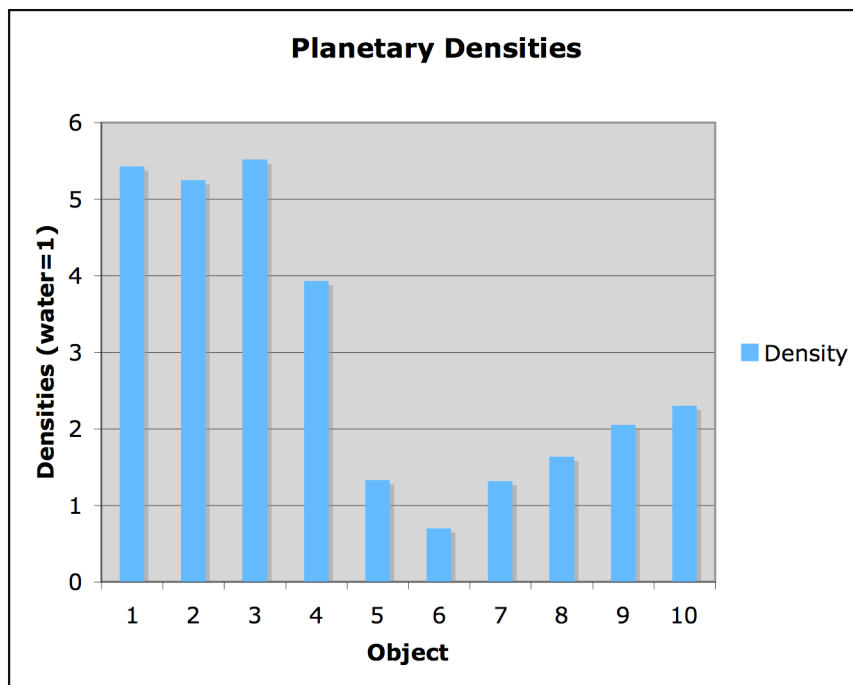
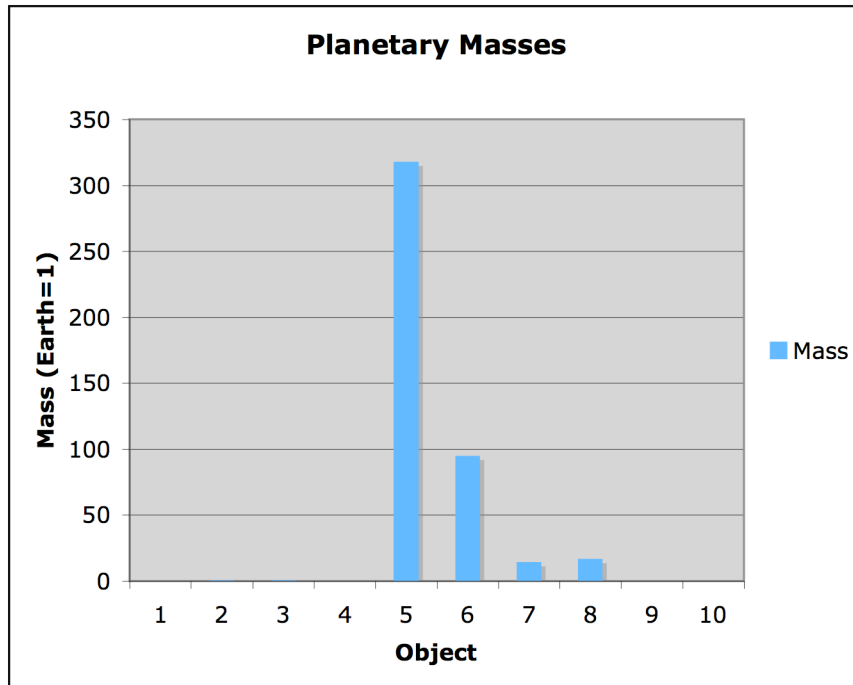


Figure 9.2.1 Histograms comparing planetary radii, masses and densities. Note-using logarithmic plots was considered, especially in the plot of planetary masses, where the only Jovian planet masses are even visible, but based on the fact that the course is non-mathematical in nature, it was decided that this may hinder the students' ability to draw conclusions from examination of the histograms.

After comparison of the histograms (similar to those in Fig. 9.2.1), the two traditional planet groups are usually established. Histograms comparing orbital radius and period and number of moons are then examined to verify the validity of the groupings. The fact that the Terrestrial planets are found closer to the Sun and the Jovians farther away is also an important fact that needs to be established prior to coverage of the formation of the solar system which is coming during the next class period. Students usually do not perceive the much longer rotational periods of Mercury and Venus than Earth and Mars as supporting the Terrestrial grouping, but can be convinced that the similar rotational periods of all four Jovian planets support their grouping.

Exposing students to the fact that not all data examined will necessarily support the groupings provides the lesson that, in science, it is rare for all measurements to fit exactly into specific categories and that when they do not, attempts should be made to explain the exceptions. This also provides the opportunity to suggest that Mercury and Venus' rotation periods being so much longer *are* considered exceptions. Mercury's rotation is tidally locked with its revolution around the Sun and Venus' may have been slowed down by friction with its extremely dense atmosphere or by other factors. (Bennett, et al. 2009)

Since tutorials are designed to be used for guided inquiry and *not* to completely replace lectures, a brief introduction explaining that comparative planetology consisting of the examination of data and attempting to identify both similarities and differences between planets is given prior to the activity along with a discussion afterward to sum-up the main points; the planetary categories identified, which planets fit in to each category and why. Occasional interjections by the instructor at certain points in the tutorial, asking students their answers to certain questions can help keep students "on-task" and prevent some students from getting on the wrong track early in an activity and then ending up completely lost by the end. (Prather et al., 2005) This has been observed to happen when some students were not occasionally given guidance on "where" they are headed.

9.3 Assessment

Examination of the above tutorial collected from students over the initial two semesters of the study showed a majority correctly identifying the members of the Terrestrial and Jovian planet groups. They also properly identifying the properties that group members had in common as opposite those properties in the other group, i.e. large vs. small, far from the sun vs. close. Nearly all students identified Pluto and Eris as not fitting in to either major group. Interestingly, without prompting by the tutorial or from instructors, nearly a third of students unexpectedly identified Pluto and Eris as members of a third group of objects. This is of course in line with present thinking that these objects, also now called “*dwarf-planets*” are members of the outer solar system population known as the *Kuiper-belt*. (Bennett et al., 2009)

The following items were part of a 25-question *Solar System Survey* given both prior to and after solar system instruction (the development, use and results of the entire survey will be discussed in Chapter 13).

1. Which is NOT considered an Earth-like (or *Terrestrial*) planet, a planet with enough properties similar to Earth to be considered the same type of planet?
 - a. Mercury
 - b. Venus
 - c. Mars
 - d. Pluto
 - e. [All of the above ARE considered Terrestrial planets]

2. Which is NOT a property of the Earth-like planets of our solar system when compared to the other type of planet?
 - a. Smaller and less massive
 - b. Closer to the sun
 - c. More rocky and metallic composition
 - d. Lower density
 - e. [All of the above ARE properties of Terrestrial planets]

3. Which IS (are) considered Jupiter-like (or *Jovian*) planets, planets with enough properties similar to Jupiter to be considered the same type of planet?
- a. Saturn only
 - b. Uranus and Neptune
 - c. Saturn, Uranus and Neptune
 - d. Saturn, Uranus, Neptune and Pluto
 - e. [None of the above; Jupiter is in a class by itself]
4. Which IS a property of the Jovian planets of our solar system when compared to Terrestrial planets?
- a. Low densities
 - b. Farther from the Sun
 - c. High mass
 - d. Ring systems
 - e. [All of the above]
5. Why is Pluto no longer considered a planet?
- a. Its orbit
 - b. Its composition
 - c. It does not fit into the major planet categories
 - d. [It is actually only one of a group of many objects of similar size, composition and orbit; so all of the above]
 - e. [Actually, since its mass is solid, Pluto is considered one of the Terrestrial Planets]

Eight sections of approximately 30 students each, taught by two different instructors, as in all part of the project to minimize instructor bias, participated in the assessment over the Fall 2008 and Winter 2009 semesters. Two sections each term (one taught by each instructor) did the activity while two (also one taught by each instructor) were given a lecture on planet-types that centered around inspection of the histograms. (Kuhn, 1989)

Results of the assessment are shown in Table 9.3.1 and Figures 9.3.1 and 9.3.2.

	% Correct	% Correct	% Correct		
	Pretest	Posttest	Posttest	Gain	Gain
Item #	N=200	(Lecture) N=87	(Tutorial) N=81	g-lecture	g-tutorial
1	36	67	68	0.48	0.5
2	22	44	43	0.28	0.28
3	45	76	82	0.57	0.67
4	46	79	84	0.62	0.7
5	39	58	53	0.3	0.23
Average	37.6	64.8	66	0.45	0.476
Standard Error	± 3.9	± 5.7	± 7.2	± 0.07	± 0.1

Table 9.3.1 Percentage of correct responses to questions on pre and posttests and normalized gains during Fall 2008 semester.

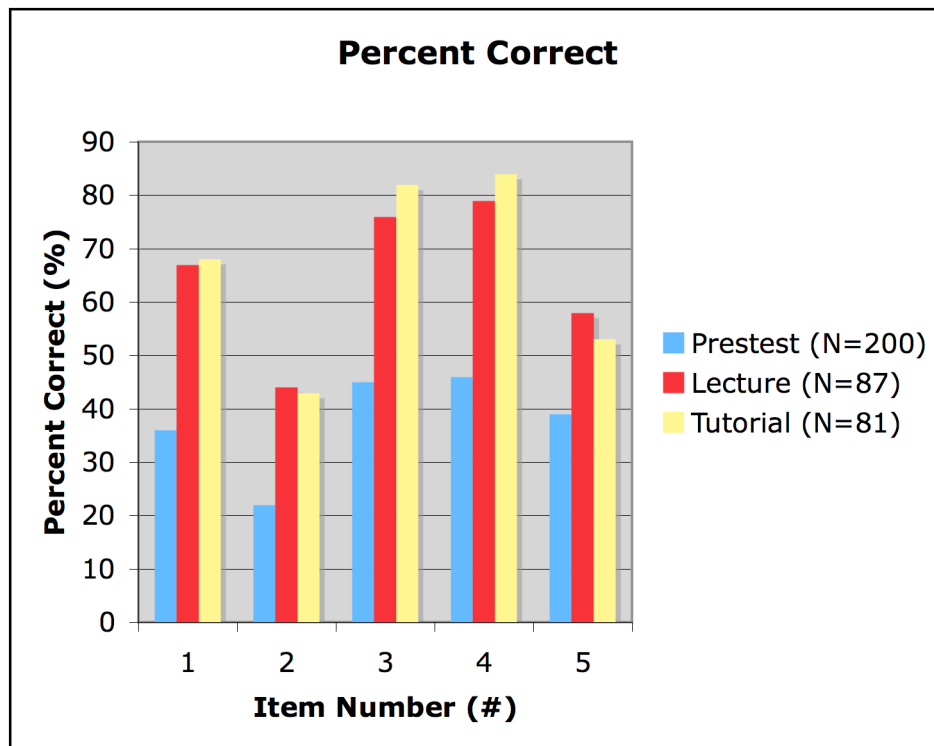


Figure 9.3.1-Percentage of correct responses to each item in pretest (blue) and the posttest for lecture sections (red) and tutorial sections (yellow).

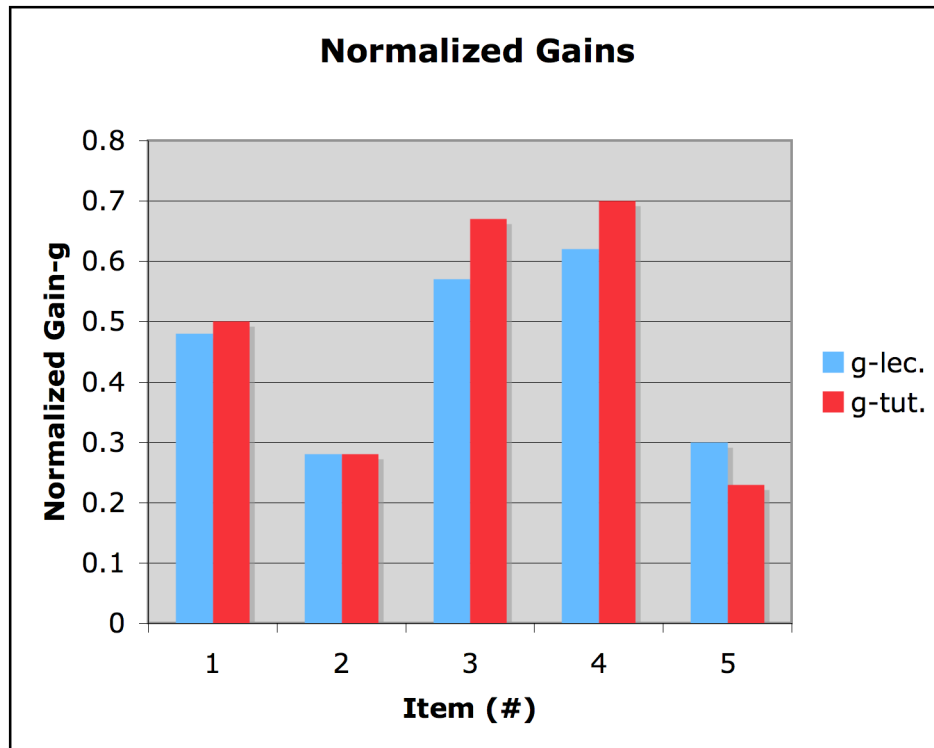


Figure 9.3.2 Normalized gains (Hake, 1998) for each item in the assessment from lecture (blue) and tutorial (red) sections.

The results clearly do not show a significant difference between the groups that did the activity rather than hearing the lecture. This could suggest that that the tutorial is not any more effective than a lecture on the subject. It could also be because the assessment questions, since they stress the difference between the types of planets, are more factual than conceptual. This could also mean that a tutorial on the this subject is not really of any benefit.

However, anecdotally, at least, consistently from semester to semester, a number of students made a point of commenting to their instructors that they enjoyed that particular day of class. This was of course encouraging and prompted a modified second trial of the study the following semesters.

The positive student reaction could also be due to the fact that the tutorial makes significant use of three of the four HPL learning environments. The pedagogy is clearly learner and community centered, since the students work the tutorial in groups. Perhaps most important, the pedagogy is also knowledge-centered, in that successful completion of the tutorial required the appropriate use of facts about the planets provided. Learning facts, in this case planetary data, by using them in a conceptual framework, in this case defining the different types of planet, rather than simply memorizing them is an excellent example of a knowledge-centered environment and although assessment scores did not clearly show it, may have been the reason students seemed to like the activity. This will be discussed in further detail at the end of the chapter.

Also, at this point, the activity was not really assessment centered, but as will be seen in the next section, changing it to be so, did seem to make it more effective.

9.4 Another Trial

The following semester, Fall 2009, the activity was implemented in the fashion of the recommended use of tutorials (Prather et al., 2009), reflecting the HPLS recommendations for effective science instruction. (Donovan & Bransford et al., 2005) Initial discussion was enhanced by the use of the above assessment questions asked in a classroom response/“clicker” format (Duncan, 2007) with flashcards with the letters of the choices printed on them. The questions were posed to students prior, diagnostically (Bransford et al., 2000) to the introductory discussion and tutorial in three sections taught by one instructor. Also, since, as discussed above, the previous semester’s results showed that there may have been very little advantage in having the students plot the histograms of the planetary data, the plots were included (appearing as in Figure 9.2.1) with the same tutorial as was supplied to students the previous semester. This would allow more time to be spent on inspection of the histograms prompted by questions from the tutorial rather than plotting them. Three other sections, one each taught by other instructors received lectures only.

After the tutorial, at the beginning of the next class period the questions were asked again as a review, formatively, only in the sections that did the tutorial, not in the sections that received the lecture. following the general rule (Duncan, 2007) is that if less than if two-thirds of responses to a question are correct, students should be instructed to discuss their answers in a “peer instruction” (Mazur, 2007) or “think-pair-share” style (Slater & Adams, 2003) with others who responded differently. After discussion another vote was then taken that usually showed dramatically improved results, often with nearly 100% agreement on the correct response.

The normalize gains from the pretest scores for both groups are shown in Table 9.4.1 and Figures 9.4.1 and 9.4.2.

	% Correct	% Correct	% Correct	g	g
Item	Pretest N=144	Posttest (Lecture-only) N=49	Posttest (HPL) N=72	lecture-only	HPL
1	50.7	79.6	77.8	0.59	0.55
2	20.8	53.1	55.6	0.41	0.44
3	43.8	77.6	84.7	0.60	0.73
4	28.5	67.3	76.4	0.54	0.67
5	29.9	44.9	61.1	0.21	0.45
Average	34.7	64.5	71.1	0.46	0.56
Standard Error	±4.9	±6.1	±4.9	±0.073	±0.044

Table 9.4.1 Results for both groups in the Fall 2009 semester.

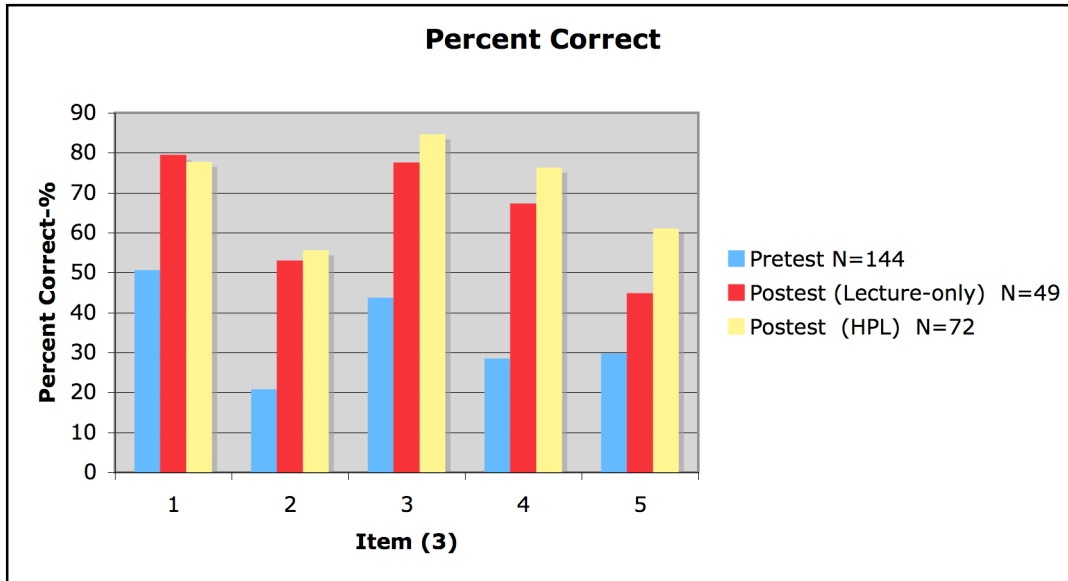


Figure 9.4.1 Percentage of correct responses in the second part of the study to each item in pretest (blue) and the posttest for lecture sections (red) and tutorial sections (yellow).

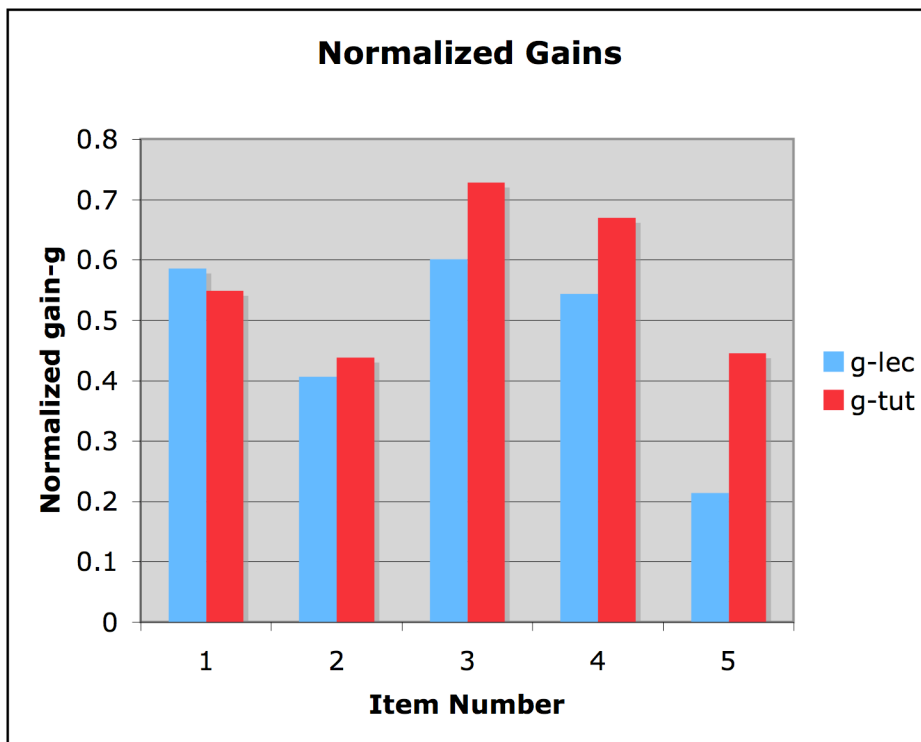


Figure 9.4.2 Normalized gains from the second part of the study for each item in the assessment from lecture (blue) and tutorial (red) sections.

The assessment data from this second part of the study does show more of a difference between the average percentage of correct responses and normalized gains between student groups that did the tutorial in conjunction with classroom response questions when compared that received lecture-only. Their scores are also higher than those that did the tutorial in the first trial. However, there is still overlap in the standard error, so the result is still not statistically significant.

Similar to in the pilot-project discussed in Chapter 7, the slightly increased differences are likely again verifying the well-documented effectiveness of the use of classroom-response/"clickers" and especially when used in conjunction with learner-centered activities such as tutorials. Since classroom response was used for both diagnostic and formative assessment this is in line with HPL pedagogy (Bransford et al., 2000) and the recommended use of tutorials and the HSLS recommendations. (Donovan & Bransford, 2005, Prather et al, 2009)

More time being available to analyze the histograms rather than being spent plotting them could also have been a factor in the greater gains by the sections doing the tutorial in the second trial than in the first.

It is unclear why students doing the tutorial in either trial out-performed students receiving lecture-only by so much more on the question about why Pluto is no longer considered a planet (the fifth assessment question) than on the other four. Especially when this *did not* happen in the first trial.. It could, however, be due to the fact that the topic would have been discussed in more detail in the second trial when diagnostic and formative assessments were used.

9.5 A Third Trial

In an attempt to see if there was indeed any advantage to use the tutorial itself or if most of the advantage was due to the use of clickers, another trial in which no sections received formative assessments in a classroom response format was run during the Fall

2010 semester. Two sections each taught by a different instructor received lectures on comparative planetology, while three sections, all taught by a third instructor, did the most recent version of the tutorial. As with data taken during this time mentioned in the previous chapter, none of the sections involved were taught by the author, again in the hope of minimizing instructor bias and the Hawthorne effect. (Hake, 1998, from Slavin, 1992) Also, at the suggestion of the instructors involved, largely based on feedback from students about which questions or parts of questions may have been confusing or unclear, the assessment questions used were modified to read as follows;

1. Which planet (s) is (are) considered planets with enough properties similar to Earth to be considered the same *type* of planet as Earth?

- a. Mercury
- b. Venus and Mars
- c. Mars only
- d. Mercury, Venus and Mars

2. Which is NOT a property of the Earth-like planets of our solar system when compared to the other planet-type?

- a. Smaller and less massive
- b. Closer to the sun
- c. More rocky and metallic composition
- d. Lower density

3. Which planet (s) is (are) considered planets with enough properties similar to Jupiter to be considered the same *type* of planet as Jupiter?

- a. Saturn only
- b. Uranus and Neptune
- c. Saturn, Uranus and Neptune
- d. Uranus, Neptune and Pluto

4. Which of the Jupiter-like (Jovian) planets of our solar system have ring systems?
 - a. Saturn only
 - b. Jupiter and Saturn only
 - c. Saturn, Uranus and Neptune
 - d. Jupiter, Saturn and Uranus and Neptune all have rings

5. Pluto is currently considered a member of which group?
 - a. The Earth-like (terrestrial) planets due to its solid composition
 - b. The Jupiter-like (Jovian) planets due to its distance from the Sun
 - c. The asteroid-belt due to its size
 - d. The Kuiper-belt due to its proximity and similarity to the other objects there.

	% Correct	% Correct	% Correct	g	g
Item	Pretest N=116	Posttest (lecture) N=36	Posttest (tutorial) N=65	lecture	tutorial
1	27.6	80.6	89.2	0.73	0.85
2	44.8	86.1	84.6	0.75	0.72
3	48.3	86.1	98.5	0.73	0.97
4	18.1	63.9	93.8	0.56	0.92
5	46.6	80.6	89.2	0.64	0.80
Average	37.1	79.4	91.1	0.68	0.85
Standard Error	±6.0	±4.1	±2.4	±0.04	±0.04

Table 9.5.1 Results for both groups in the Fall 2010 semester.

The data in table 9.5.1, plotted in Figures 9.5.1 and 9.5.2, shows that this time, students that did the tutorial did outperforming those who received lectures on four of the five items on the assessment. The tutorial group's average percentage score and normalized gains were also higher with no overlap in the error bars, so the result is statistically significant. This result shows that that the tutorial can indeed be effective on its own even when not used in conjunction with classroom response formative assessments.

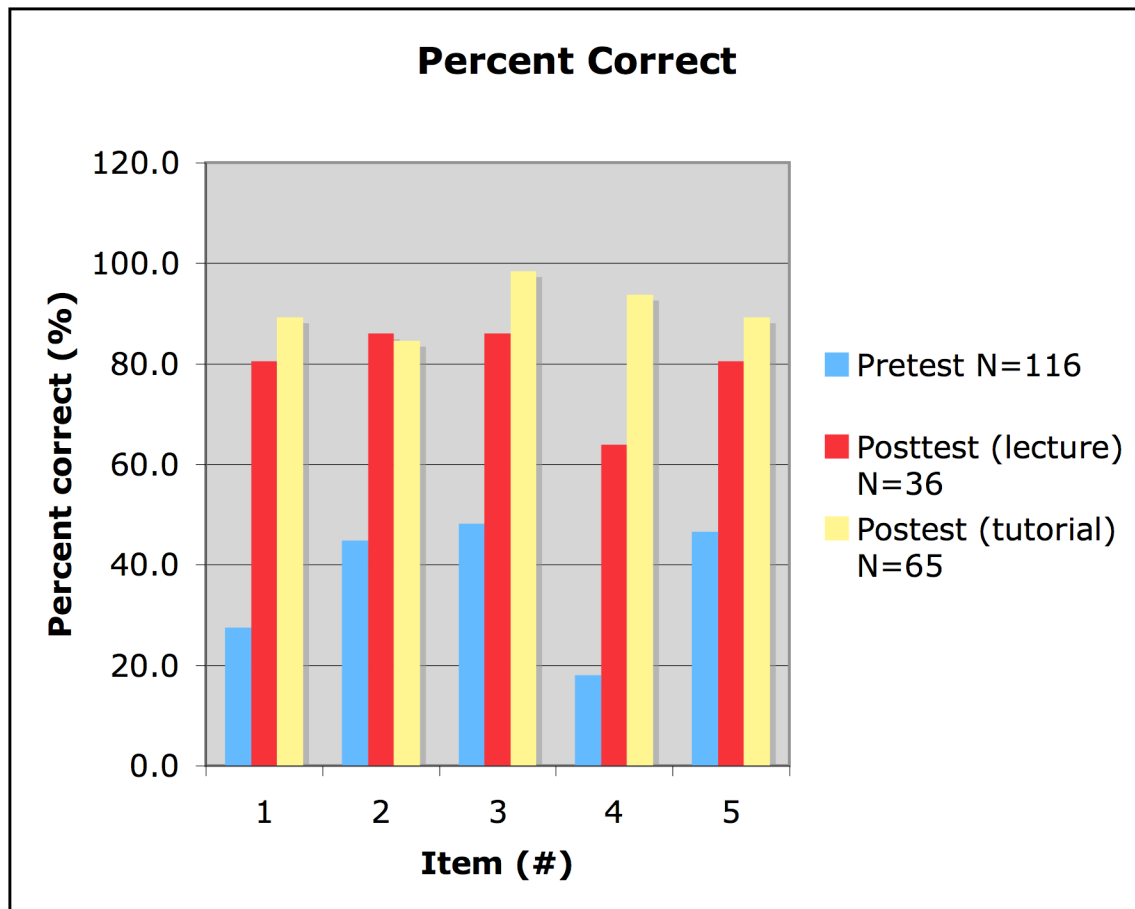


Figure 9.5.1 Percentage of correct responses in Fall 2010 to each item in pretest (blue) and the posttest for lecture sections (red) and tutorial sections (yellow).

It should be note that item 4, about which Jovian planets have rings, had the lowest pretest score and the lowest posttest score in the lecture group, which made the question with the largest discrepancy in gain between the two groups. Since it is a common misconception that Saturn is the only planet with rings (Slater & Adams, 2003, LoPresto & Murrell, 2011) the fact that all Jovian planets have rings could be surprising to many students. It is certainly likely that process of analyzing the planetary data table done by the tutorial group and not the lecture group, allowed more of the former group to retain the information, but the fact the majority of the gain was in this one particular item does somewhat diminish the overall argument that students will learn this subject better with this tutorial than with a lecture.

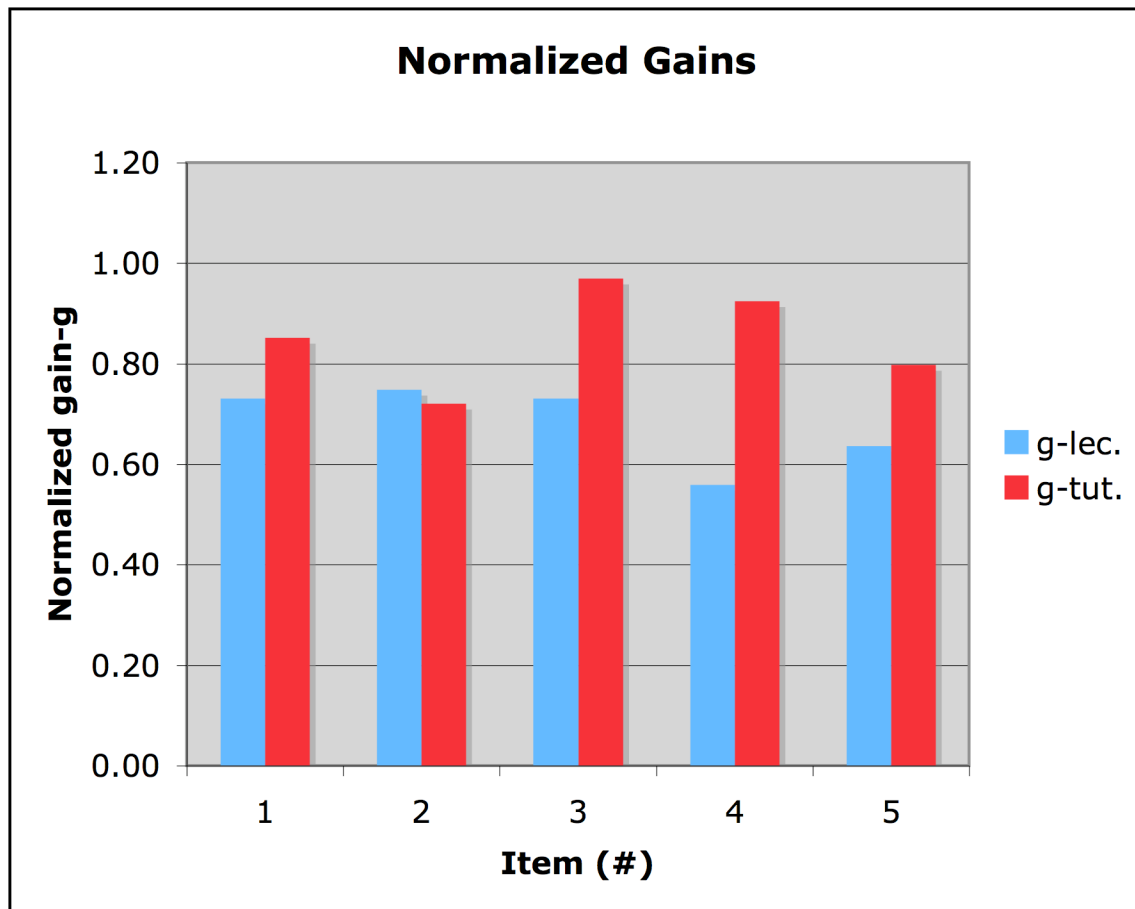


Figure 9.5.1 Normalized gains from the Fall 2010 for each item in the assessment from lecture (blue) and tutorial (red) sections.

9.6 Knowledge Centered Instruction

The activity described here is an excellent example of knowledge-centered instruction. Facts are used to teach a concept rather than just being presented for memorization. Instead of listening to an instructor use precious class time to recite data (data that can be easily found in many books, including likely the course text or online) for each planet to be memorized and later forgotten by students, the planetary data was examined by groups of students (community centered) that used it to establish that there are two different types of planets and some objects that do not fit into either category. Students were actually “doing” science rather than just hearing about someone else doing it. (Donovan & Bransford, 2005, Fucili, 2005, Percy 2005: see Pasachoff & Percy) As described, the activity is also clearly learner and assessment centered. (Bransford et al, 2000)

Chapter 10

Visual Assessments and Tutorials

10.1 Introduction

After being introduced to the types of planets through the activity described in the previous chapter, HFCC astronomy students go on to study the formation of the solar system through a lecture-tutorial. Writing, using and assessing Lecture tutorials will be the subject of coming chapters. What follows here is a description of a new pedagogy developed to study two topics covered after solar system formation; extra-solar planets and comet-orbits. Comets, discussed in this chapter, are studied as a part of solar system debris. This includes asteroids, meteors and the Kuiper belt.

10.2 Visual Assessments and Tutorials

In visual assessments and tutorials, students are instructed to construct and/or examine pictures and/or diagrams related to the topics being studied, rather than, as during traditional lectures, simply be shown the pictures and diagrams. Again, the specific subjects studied here are comet-orbits in this chapter and extra-solar planets in the next. These are two solar system topics often covered in introductory astronomy that are very visual in nature and therefore lend themselves to being studied this way. As in previous chapters, the tutorials completed by the students will be assessed and their effectiveness compared to that of traditional lectures about the same topics. The lectures, in this case, feature diagrams similar to those constructed or examined in the visual assessments and tutorials. (LoPresto, 2010)

10.3 Comets (Procedure)

During the Winter 2009 semester N=93 students in four sections of introductory astronomy taught by two different instructors were given a diagnostic assessment that consisted of a diagram of the portion of a comet's eccentric orbit near the sun (see Figure 10.3.1). They were instructed to draw the comet at five specified positions showing differences in the relative size of the coma and the tail and differences in the direction of the tail in each position. The students were asked to do this prior to any instruction at the

beginning of the class period in which comets were to be covered. The only previous exposure to the material was part of assigned reading of the chapter in their textbook about asteroids, comets and dwarf planets. (Bennett et al., 2009) In their reading they encountered a diagram showing the correct proportions and directions of a comet's coma and tail at different points in the orbit. Most students had turned in assigned written review questions from the end of the text chapter, which suggests that they had indeed done the reading.

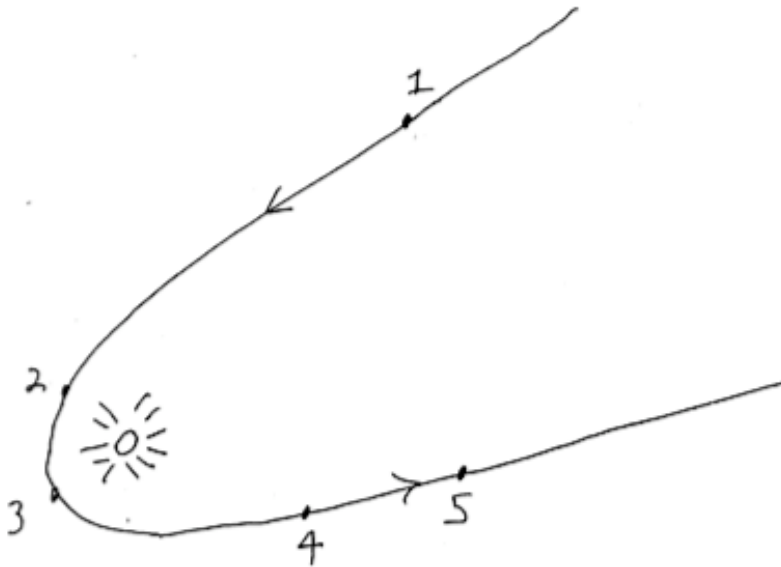


Figure 10.3.1 The diagram of a comet's orbit that was given to students at the beginning of the class period in which comets were to be covered and at the beginning of the next class period after instruction. The following instructions were included; Figure 1 shows the portion of a comet's highly eccentric orbit that is close to the Sun. At each numbered position of the comet's *nucleus* draw the comet's *coma* (head) and *tail*. *Make sure that your drawing clearly shows any differences between the size of the coma and length of the tail and the direction the tail is pointing.*

Only 23% of the drawings (18/93) correctly showed the changing directions of the tail. 13% (12/93) showed the correct changes in the relative size of the tail. Only just over 4% (4/93) showed the correct changes in the size of the coma.

Nearly half, 46 % (43/93) of drawings betrayed a popular misconception, that comets always travel head first and tail last (see Fig. 10.3.2 for a student example). This is an understandable misconception, based both on the usual meanings of the terms “head” and “tail” and possibly due to still-pictures of comets. Pictures, such as those found in the textbook the students were reading (Bennett et al. 2009) give the impression of a still “snapshot” image of an object in rapid motion with the tail trailing behind the head. This could also possibly be due to confusion between comets and meteors.

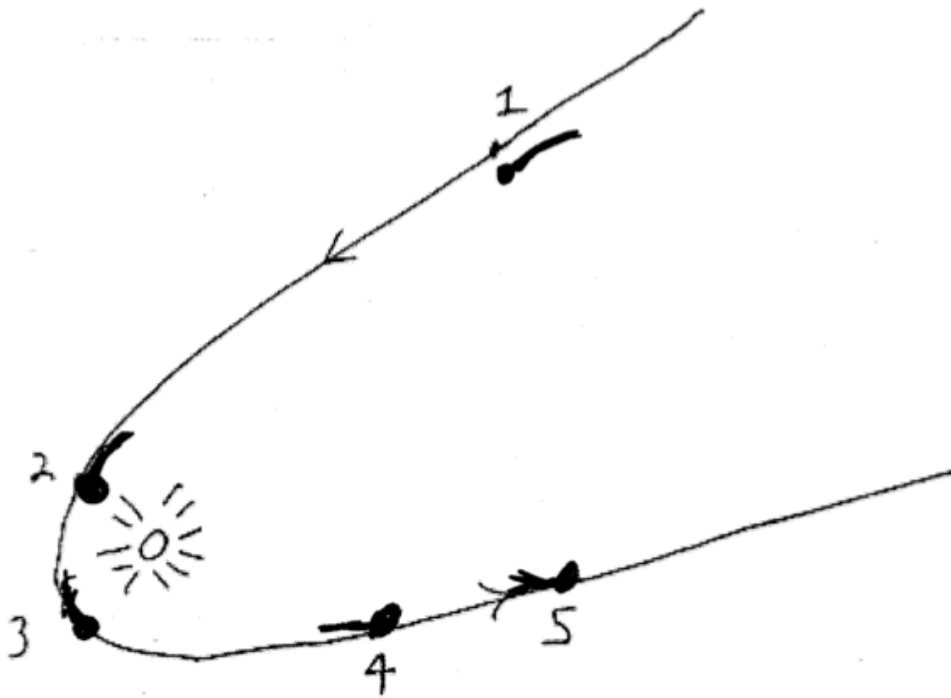


Figure 10.3.2 Student drawing showing the common misconception that a comet always travels head first and tail last.

As part of the *Solar System Survey* (Chapter 14) on the entire solar system “unit,” that students were given prior to any instruction or assigned reading on the topics, only 14% (N=100) responded correctly (choice c) to the question;

A comet's tail

- a. precedes its head through space.
- b. follows its head through space.
- c. is farther from the Sun than its head is.
- d. is closer to the Sun than its head is
- e. [None of the above]

with 45% of respondents choosing b.

Quantitative evidence for confusion between comets and meteors is shown by the following item that is part of a separate *Misconceptions Survey* (LoPresto, Murrell 2011) that was given to the same population at the beginning of the semester.

A "shooting star" or "falling star" is

- a. a star falling to Earth.
- b. a comet streaking across the sky.
- c. a meteor falling through the atmosphere.
- d. [either B or C above-comets and meteors are the same thing]

31% of respondents (N=115) did correctly respond “c,” but 60% chose “b” or “d” (30% each) showing the confusion. Incidentally, only 9% responded “a” which is encouraging.

Two sections (one taught by each instructor) were given a traditional lecture on solar system debris, including comets, in which they were shown a figure depicting a comet’s orbit featuring the *correct* changes in relative coma and tail size and tail direction. That

radiation from the Sun is the cause of the changes was emphasized with the explanation that since the tail is material being “thrown-off” the comet by heat from the sun, it will always point away from the Sun, approximately in the direction of the Sun’s “rays.”

The other two sections (again one taught by each instructor) were given a short visual tutorial (see Appendix 10.1) with explicit directions for correctly drawing the comet’s coma and tail (in Figure 1 in the tutorial) as well as an exercise in which they were asked to match each numbered position in the comet’s orbit (Fig. 2 in the tutorial) with arrows that best represented the direction of the comet’s tail. Having each instructor teach one sections by lecture and one with the visual tutorial was an attempt minimize any *instructor-bias*, as defined in Chapter 7, in the results.

As is recommended when using tutorials, a short “debriefing” discussion occurred after the tutorial was completed (Prather & Brissenden, 2009, *Lecture Tutorials*, Prather et al. 2005)in which the correct coma and tail sizes and directions were discussed.

10.4 Comets (Results)

At the start of the next class session students in all sections were again given Fig. 10.3.1 Since the assessment was prior to any evaluation for the purpose of determining a grade and was still part of the learning process, it can be considered formative. See Table 10.4.1 below for the results.

		% Correct	% Correct	% Correct	Gain	Gain	Chi – squared test
Item		Diagnostic N=93	Formative (lecture) N=40	Formative (tutorial) N=47	g lec.	g tut.	P-value
1	Coma size	4	18	46	0.15	0.46	0.0001
2	Tail length	13	33	70	0.33	0.66	0.0026
3	Tail direction	23	65	76	0.55	0.69	0.2467
4	Misconception	46	20	6			0.0003

Table 10.4.1 Percentages of students drawing the coma and tail size and tail direction correctly on Fig. 10.3.1 before and after instruction by lecture and tutorial. Note that the fourth row is the number of students who’s drawing still showed the head first, tail last misconception, so a decrease in the percentage is the desired result.

The sections that did the tutorial, $N=47$, did even better, 46% of drawings had the coma's relative size correct, 70%, $g=0.66$ the tail's relative size and 76%, $g=0.69$ correctly showed the changes in tail direction. Figure 10.4.1 is an example of what was considered a drawing correctly showing the changes in coma and tail size and tail direction.



Figure 10.4.1 Student drawing showing correct variations in size of the coma and tail as well as correct orientations of the tail. Note- all students were taught in lectures that there are two tails on a comet but this was not considered part of this exercise (some students however did include two tails in their drawings).

20% of the students taught by lecture still submitted drawings similar to Fig. 10.3.2, showing the head first, tail last misconception while only 6% of those taught with the tutorial did so. Fig. 10.4.2 is a histogram showing the percentages of correct responses on the assessment before and after instruction by lecture and tutorial. Fig. 10.4.3 shows normalized gains, g .

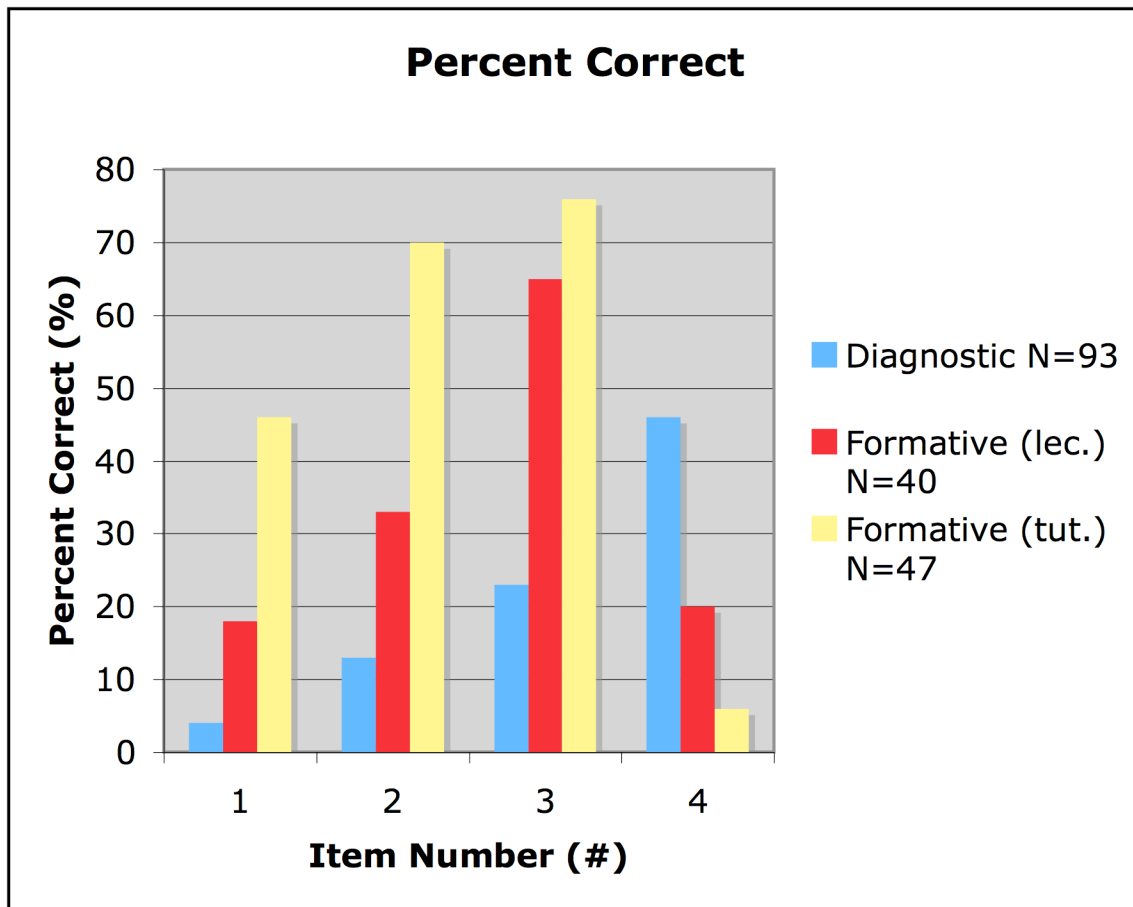


Figure 10.4.2 Percentage of correct drawings for each item the diagnostic assessment (blue) and formative assessment in lecture sections (red) and in tutorials sections (yellow). Item 1 is the relative sizes of the coma; 2 the relative sizes of the tail; and 3 is the directions of the tail. Item 4 is the percentage in each group that made a drawing like Fig. 10.3.2, the head first, tail last misconception, so correct responses for this item will show a decrease.

The P-values reported in the last column of Table 10.4.1 are from chi-squared tests with a 2 x2 contingency table comparing the numbers of correct and incorrect items in the drawings submitted by the members of the lecture and tutorial groups. The P-values are very small (much less than $P=0.05$) for the comparison of the first and fourth items, the size of the coma and the common misconception about tail direction and small for the comparison of the second item on coma-size. The difference between the two groups in

the third item is less significant. This item, the tail direction, although still submitting fewer correct responses than the students in the tutorial sections, was by far the item on which students in the lecture sections did their best. This suggests that the changes in the tail's direction are what is most obvious to students when simply looking at a diagram of a comet's orbit, while the other changes are much more likely to be recognized by students who actually construct the diagram.

These much higher gains by students in the sections that completed the tutorial in which they were required to draw the comet at the various points in its orbit compared to students in the section that were just shown a diagram of a comet's orbit during a lecture on solar system debris is consistent with previous findings that have shown that student learning gains will be higher when they are actively engaged (Wandersee et al., 1994, Hake, 1998, Bransford et al. 2000, Weimer, 2002, Donovan & Bransford, 2005, Lasry et al., 2008)

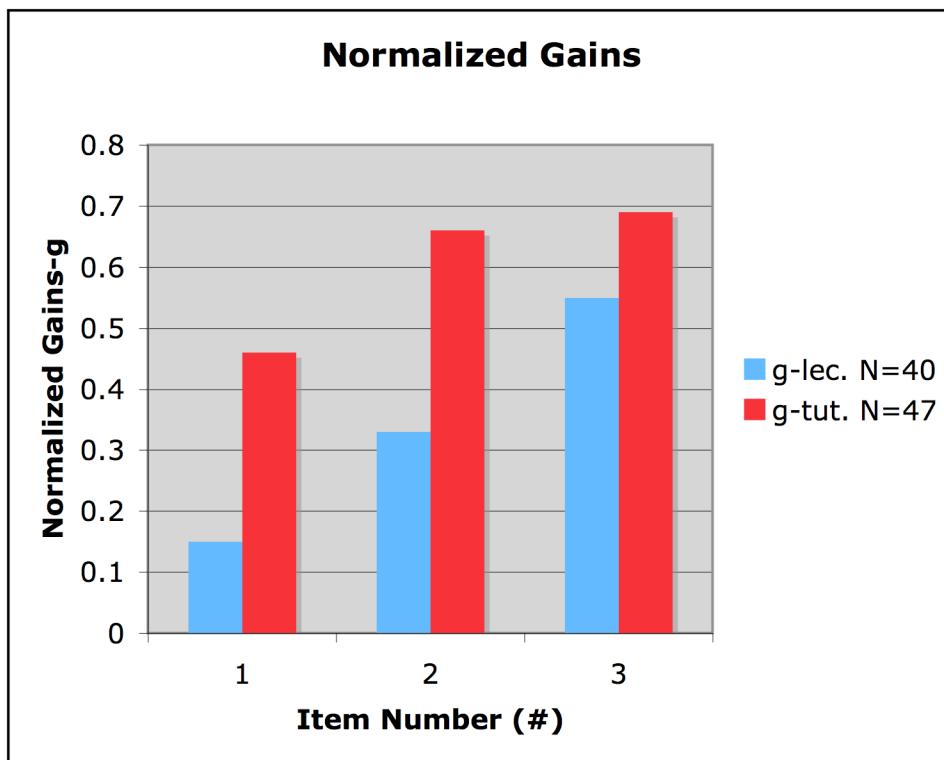


Figure 10.4.3 Normalized gains, g , on items from the diagnostic to the formative assessment in the lecture sections (blue), and in tutorial sections (red).

When the *Solar System Survey* was used as a posttest a week after the exam on solar system topics, correct responses to the above multiple-choice question on the direction of a comet's tail, paralleled results of the visual assessments (Table 10.4.1), with 48%, $g=0.4$ correct responses in the lecture sections and to 55%, $g=0.48$ in the tutorial sections. The percentage still choosing "b" was 26% in the lecture sections and 18% in the tutorial sections.

In another item from the *Solar System Survey*;

Which part of a comet DOES NOT appreciably change in size as the comet approaches or recedes from the sun?

- a. nucleus
- b. coma (head)
- c. tail
- d. [neither b nor c change, only a does]
- e. [no part of a comet changes with proximity of the sun]

percentages of correct responses, "a," in the lecture group went from 35% on the pretest to 46%, $g=0.17$ on the posttest and to 63%, $g=0.43$ in the tutorial sections, again.

		% Correct	% Correct	% Correct	Gain	Gain
		Pretest N=100	Posttest (lecture) N=46	Posttest (tutorial) N=38	g-lec.	g-tut.
1	Tail direction	14	48	55	0.4	0.48
2	Change in size	35	46	63	0.17	0.43

Table 10.4.2 Percentages of students correctly answering multiple-choice items from the *Solar System Survey* on comet tail direction and on what part of the comet does not change in size before and after instruction by lecture and tutorial.

The visual assessment shown in Fig. 10.3.1 was given third-time, as a summative assessment at the same time as the *Solar System Survey* was given as a post test, a week after the exam on solar system topics, approximately three weeks after the described coverage of comets. Note that these summative assessments *were not* part of the exam. As seen in Table 10.4.3, the percentage of N=46 students from the lecture sections that correctly drew the relative sizes of the coma and tail and the directions of the tails *dropped* to 9%, 30% and 59% respectively but the percentage of drawings showing the head first, tail last misconception also dropped to 15%. Percentages correct for N=38 students from the tutorial sections *rose* to 61%, 84% and 89 % with misconceptions dropping to a 3%, a single student in that population. In summary, the students who did the tutorials not only *outperformed* those who were lectured to on a formative assessment, but seemed to show greater *retention* on a summative assessment as well. Recall that in an attempt to minimize *instructor bias*, both instructors involved in the study taught one lecture and one tutorial section each.

		% Correct	% Correct	% Correct	% Correct
Item		Formative (lecture) N=40	Summative (lecture) sum. N=46	Formative (tutorial) N=47	Summative (tutorial) N=38
1	Coma size	18	9	46	61
2	Tail size	33	30	70	84
3	Tail direction	65	59	76	89
4	Misconception	20	15	6	3

Table 10.4.3 Comparison of percentages of students drawing the coma and tail size and tail direction correctly on Fig. 10.3.1 in a formative assessment the next class period after instruction to summative assessments in sections taught by lecture and tutorial showing greater retention in the sections taught by tutorial.

10.5 Visual Tutorials and Assessments used with HPL Pedagogy

In the above comparison between the effectiveness of the visual tutorial and lecture, both the sections doing the visual tutorials and those receiving lectures participated in similar assessments at the same points in instruction. Now that the effectiveness of the visual tutorials when compared to lecture had been verified, the next step is to compare instruction with HPL pedagogy (Bransford et al. 2000) to traditional instruction by lecture only, without any diagnostic or formative assessment.

During the Fall 2009 semester the visual tutorials and assessment were used in the recommended fashion for tutorials (Prather et al. 2005; 2009) that are in line HSLs recommendations for effective science teaching. (Donovan et al. 2005) First the visual-assessments were administered diagnostically, prior to any instruction except for assigned reading, They were then dealt with immediately in an active and collaborative fashion by students exchanging and grading each other's papers based on what they believed to be correct, then returning the papers to the original owners and discussing results. Next, preceded by short introductory lectures the visual-tutorials were used for instruction followed by also short, wrap-ups or debriefings. At the beginning of the next class period, the visual-assessments were given again, this time formatively allowing the students to again compare results and discuss problems as before.

During the Fall 2009 semester, the comets visual assessment was also given at the same time as the *Solar System Survey* was administered. N=141 students took the pretest. N=72 students in three sections that were taught the topics in the manner described above took the posttest as did N=47 that received instruction on the topics by traditional lectures *only*, without *any* HPL-pedagogy.

Table 10.5.1 and Figures 10.5.1 and 10.5.2 show the results of the comparison for the comets visual-assessment. The sections taught using the visual tutorial and assessment as part of HPL-pedagogy had much greater gains than those that received only traditional lecture instruction. This time, all the P-values are smaller than $P=0.05$. Note the very low P-values for the first two items and low P-values for the last two.

		% Correct	% Correct	% Correct	Gain	Gain	Chi- square test
Item		Pretest N=141	Posttest (lec.-only) N=46	Posttest (HPL) N=72	g lec. only	g HPL	P-value
1	Coma size	5.7	8.7	69.4	0.032	0.68	0.0001
2	Tail length	7	30.4	86.1	0.25	0.85	0.0001
3	Tail direction	6.4	63	84.7	0.61	0.84	0.0085
4	Misconception	64.5	17.4	5.5			0.0203

Table 10.5.1 Percentages of students drawing the coma and tail size and tail direction correctly on Fig. 10.3.1 before and after instruction by lecture only and HPL-pedagogy using the visual-tutorial in the Fall 2009 semester. Percentages of students submitting a drawing like Fig. 10.3.2 showing the common head first, tail last at all points in the orbit misconception are also shown.

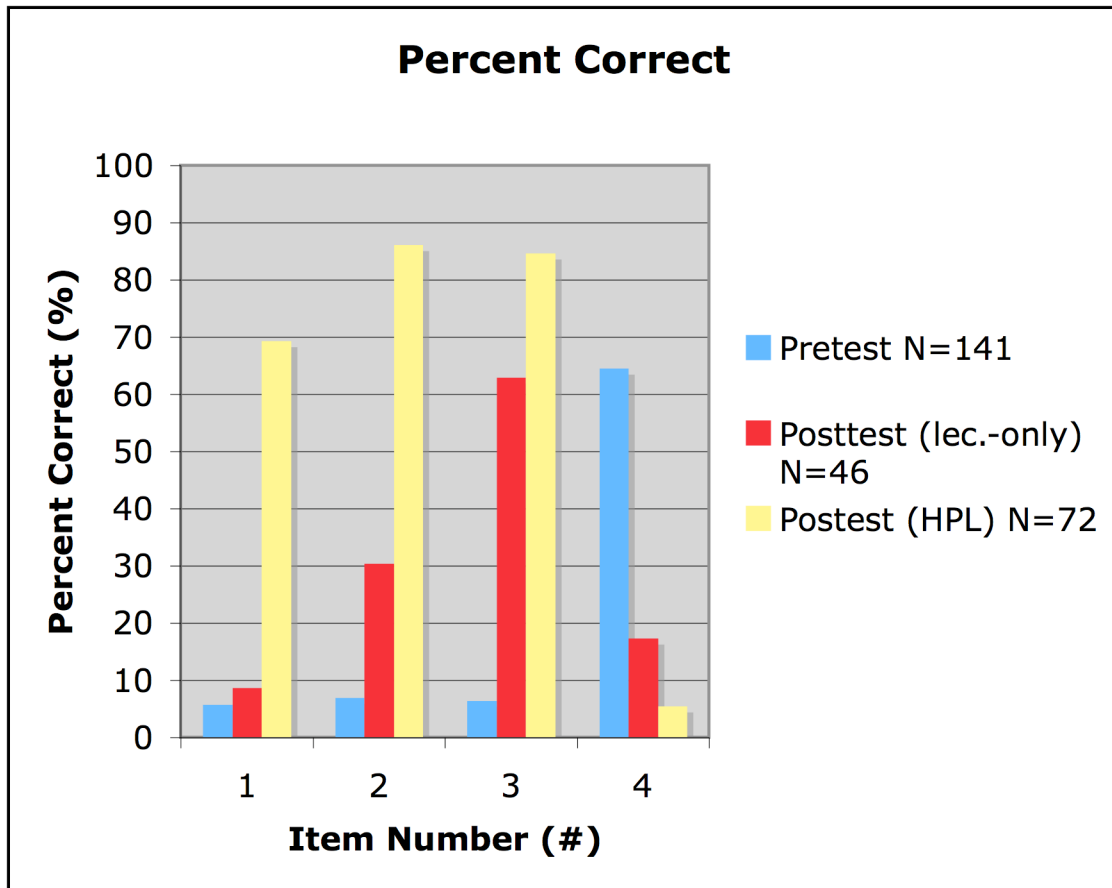


Figure 10.5.1- Percentage of correct drawings for each item the diagnostic assessment (blue) and formative assessment in lecture-only sections (red) and in HPL/ visual-tutorials sections (yellow). Recall that item 4 is the percentage of students submitting a drawing like Fig. 10.3.2 showing the head first and tail last misconception, so correct responses for this item will show a decrease.

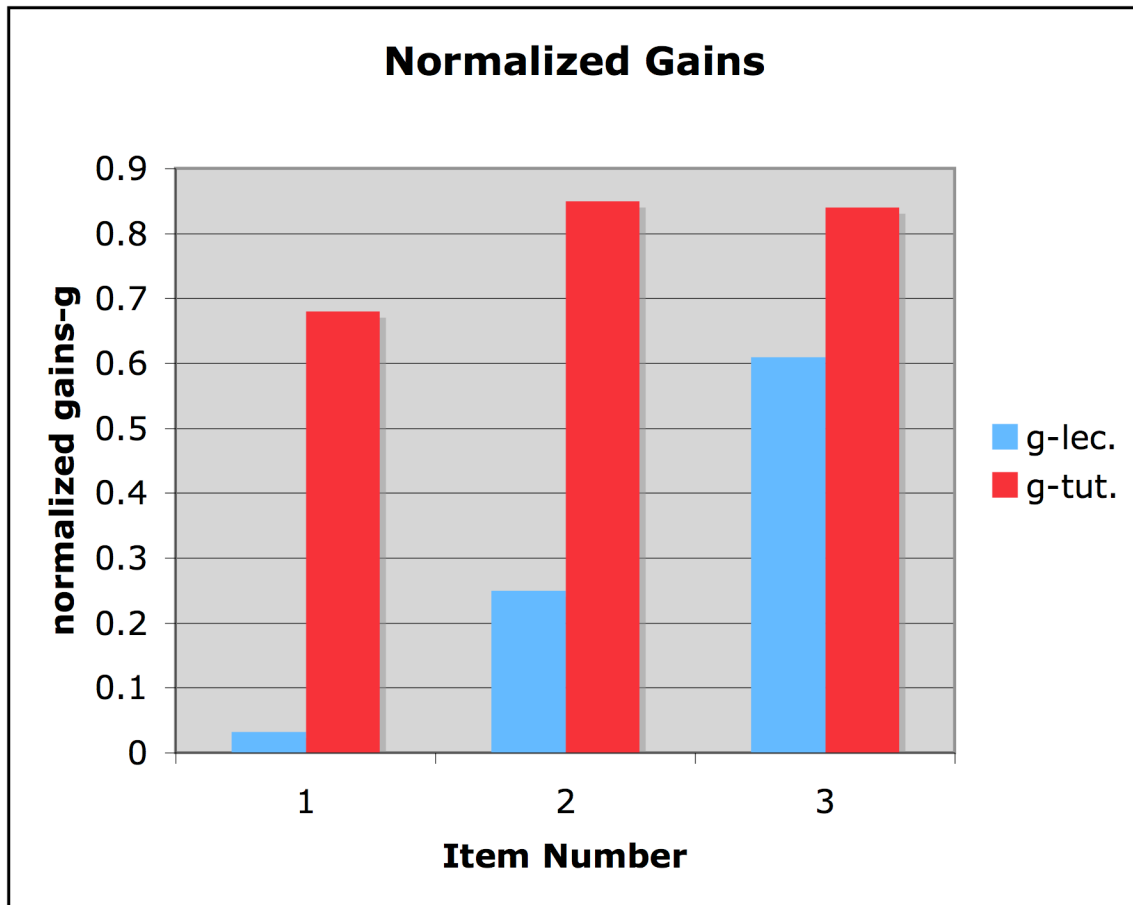


Figure 10.5.2-Normalized gains, g , on each item from pretest to posttest administration of the comets visual assessment, lecture-only sections (blue), and in HPL/ visual-tutorial sections (red). “Item” 1 is the relative sizes of the coma, 2 the relative lengths of the tail and 3 is the directions of the tail.

Note that gains on item 1, the relative sizes of the coma are extremely small for the lecture-only sections when compared to their gains on items about the comet’s tail. This is likely do to the fact that the figure (Bennet et al., 2009) that they were shown depicting changes in the comet during its orbit was more focused on the changes in the tail than the coma. Although the figure showed that the coma was nonexistent when then comet was very far from the sun, it did not clearly show changes in the size of the coma as it approached its perihelion as it did with the both the size and direction of the tail. This is more evidence of how valuable the experience of actually constructing the diagram is compared to only viewing it.

10.6 A Third Trial

As in the previous chapter, in the interest of minimizing instructor bias and the Hawthorne-effect (Hake, 1998, from Slavin, 1992), a third trial was run during the Fall and Winter semesters of the 2010-2011 academic year. The same diagnostic visual assessment as in the previous trials was given to N=110 students in 7 different sections taught by 4 different instructors, none of which were the author. N=59 students in 4 different sections received lectures on comet orbits, while N=64 students in 6 different sections completed the same visual tutorial as in previous trials. As in the previous trials the results, in Table 10.6.1 and Figures 10.6.1 and 10.6.2 , showed much greater gains on the posttest by students completing the visual tutorial than those receiving lectures and very low ($P<0.05$) P-values.

		% Correct	% Correct	% Correct	Gain	Gain	Chi- squared test.
Item		Pretest N=110	Posttest (lecture) N=59	Posttest (tutorial) N=64	g lec.	g tutorial	P-value
1	Coma size	3.6	5	67	0.032	0.68	0.0001
2	Tail length	11.8	22	83	0.25	0.85	0.0001
3	Tail direction	7.2	54	83	0.61	0.84	0.0008
4	Misconception	68	25	6.3			0.0051

Table 10.6.1 Percentages of students drawing the coma and tail size and tail direction correctly on Fig. 10.3.1 before and after instruction by lecture and using the visual-tutorial in the Fall and Winter 2010 and 2011 semesters. Percentages of students submitting a drawing like Fig. 10.3.2 showing the head first and tail last misconception, so correct responses for this item will show a decrease.

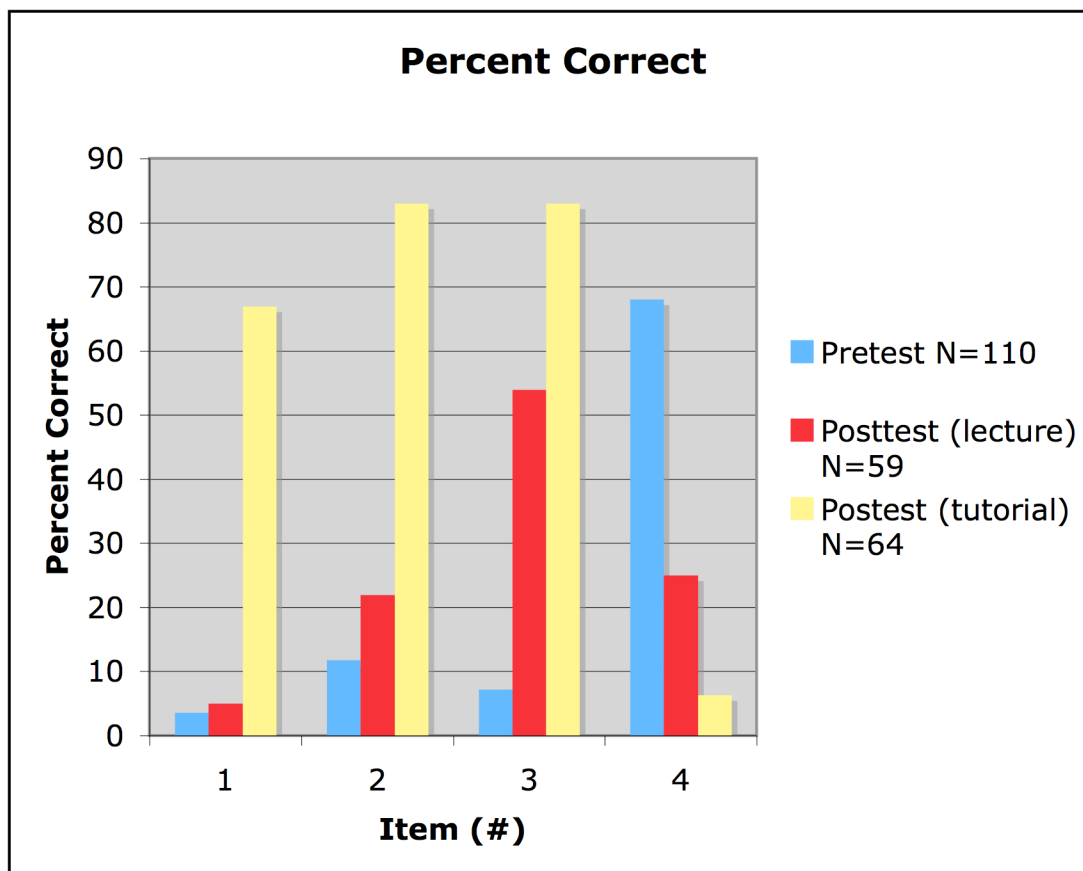


Figure 10.6.1- Percentages of students drawing the coma and tail size and tail direction correctly on Fig. 10.3.1 before (blue) and after instruction by lecture (red) and using the visual-tutorial (yellow) in the Fall and Winter 2010 and 2011 semesters. Recall that item-4 is the percentages of students submitting a drawing like Fig. 10.3.2 showing the common head first, tail last at all points in the orbit misconception.

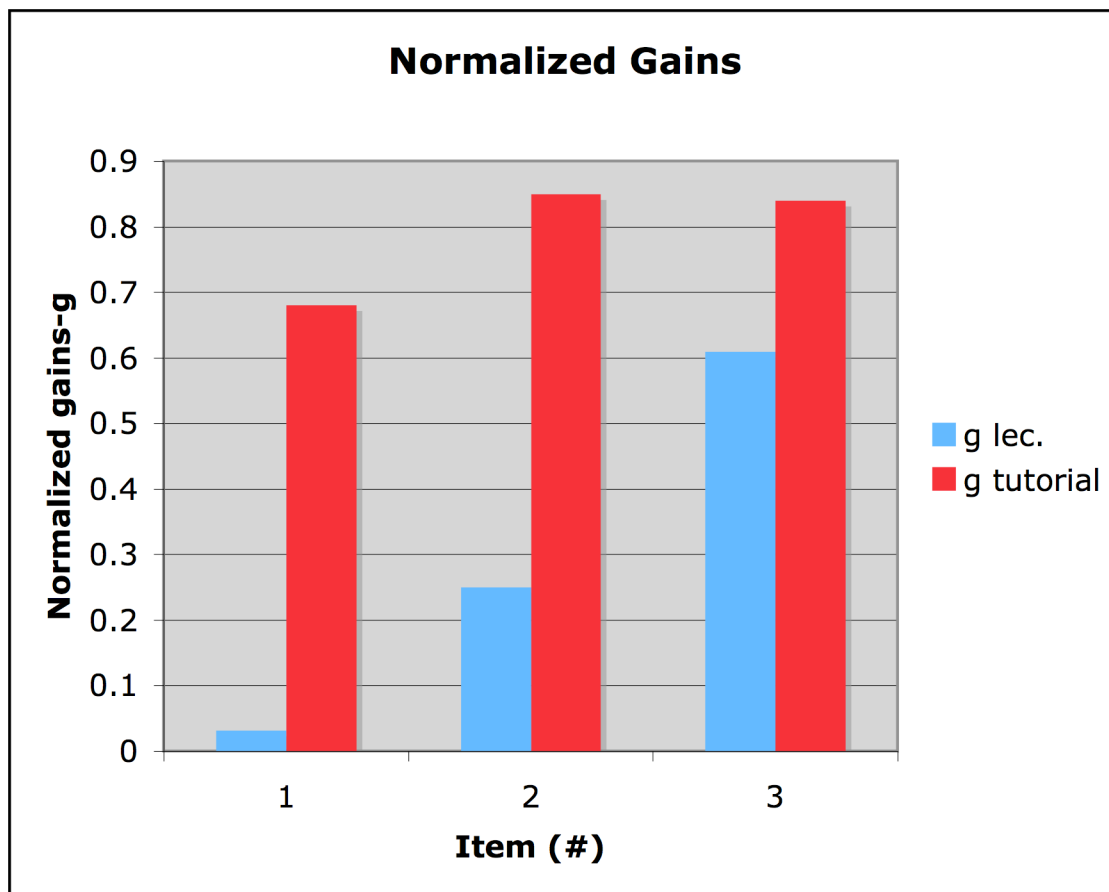


Figure 10.6.2-Normalized gains, g , on each item from pretest to posttest administration of the comets visual assessment, lecture sections (blue), and in the visual-tutorial sections (red) during the Fall and Winter 2010 and 2011 semesters. “Item” 1 is the relative sizes of the coma, 2 the relative lengths of the tail and 3 is the directions of the tail.

10.7 Learning Environments

The apparent success of the *visual tutorial* could be due to the fact that it makes use of all four of the HPL learning environments. The pedagogy is clearly learner and community centered, since the students work the tutorial in groups. It is assessment-centered since visual tutorials were accompanied by *visual assessments* that were used both diagnostically and formatively. The pedagogy is also knowledge-centered, in that successful completion of the tutorial required the appropriate use of facts about the changes that a comet undergoes during its orbit around the sun. This is especially true of a visual tutorial and assessment on the subject of extra-solar planets that will be featured

in the next chapter. In the tutorial and assessment, students determine facts about the planets from observations of changes in the light from their stars.

Chapter 11

A Visual Assessment and Tutorial on Extra Solar Planet Detection

11.1 Introduction

Another *visual-tutorial* designed for this study was on the detection of extra solar planets. As per the schedule in Chapter 6, this activity is the main focus of the third day of solar system topics and actually occurs prior to the “*Comets*” visual tutorial featured in Chapter 10.

11.2 Extra Solar Planets (Procedure)

In this visual tutorial, found in *Appendix 11.1*, plots of the varying Doppler-shifts in the spectra of stars caused by the presence of unseen planetary companions were compared with the purpose of identification of the causes of observed differences between plots. The plots will appear different for planets of different mass, orbital period (caused by differing distance from the Sun), eccentricity of the orbit and the presence of multiple planets.

Prior to any instruction, but again after assigned reading (Bennett et al. 2009) that featured the Doppler detection method for finding extra-solar planets N=84 students from the same four sections taught by the same two instructors as in the study on comets from the previous chapter in the Winter 2009 semester were asked to complete the visual-assessment shown in Fig. 11.2.1 below.

Figure 11.2.1-The visual-assessment used prior to and after instruction on detection of extra-solar planets.

Extra Solar Planet Questions

Label each description with the letter that matches the Doppler-shift plot that it most likely represents

_____ A massive planet in a close orbit

_____ A massive planet in a far orbit

_____ A lighter planet in a close orbit

_____ A lighter planet in a far orbit

A



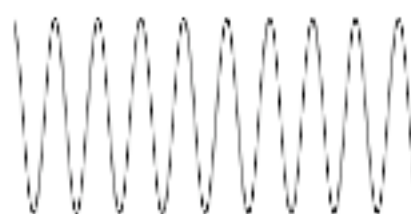
B



C



D



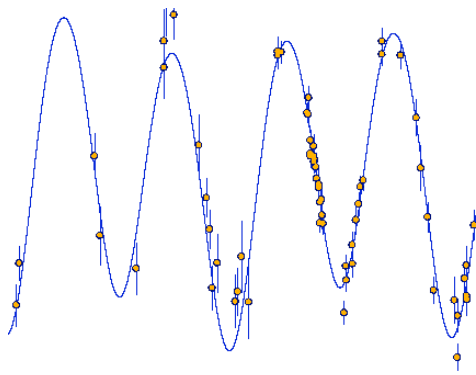
Choose which plot below represents;

_____ a planet in an eccentric orbit

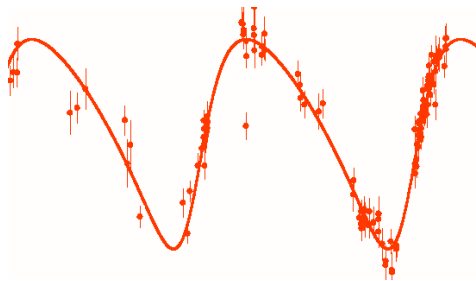
_____ a multiple planet system

_____ a planet in a circular orbit

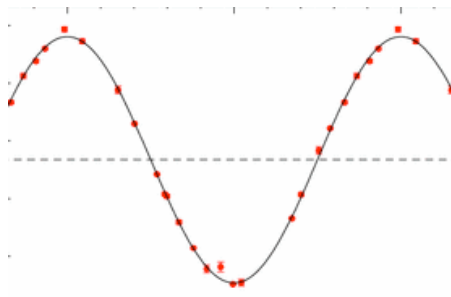
E



F



G



With each response being scored as 1 point, students averaged $3.6/7=51\%$ on the diagnostic assessment. $22/84=26\%$ answered all four parts of item- 1 on the front page, showing the effects the of the properties of the planet on the waveforms of the changing Doppler-shifts, correctly and $45/84=53\%$ answered all three parts of item- 2 on the back page, on whether the waveform indicates a circular or eccentric orbit or the presence of multiple planets, correctly.

In the same fashion as with the instruction on comets, students in two sections (one taught by each instructor to minimize instructor bias) received lectures on extra solar planet detection that featured the website www.exoplanets.org as a visual aid. Two other sections (one taught by each instructor) received a brief introductory lecture on the Doppler-detection method for finding extra solar planets and then were asked to complete the visual-tutorial *Extra Solar Planets* found in *Appendix 11.1*. The lecture contained the same information as the introductory paragraph of the visual tutorial. The visual-tutorial stresses student examination and construction of diagrams of how the waveforms of the plots of the changing Doppler-shifts in the light of a star are affected by planetary mass and orbital properties, including orbital eccentricity, and the presence of multiple planets. These are the same concepts covered in the visual-assessment above. (Note-Figures in the second part of the visual assessment and in the visual tutorial in *Appendix 11.1* were used with permission from the *Webmaster* at www.exoplanets.org).

Note that *all* sections were given a simple demonstration of the Doppler-effect with sound waves. A microphone attached to a cord and emitting a high-pitch tone was rotated by in the instructor in the plane parallel to the floor so that students could hear the changes in pitch as the microphone was moving toward or away from them. The analogy between the pitch of sound an the color of light both being caused by the wavelength and frequency of the sound or light was then discussed. It should also be mentioned that, as with most tutorials, the overall amount of time spent on the topic is about the same in sections that do tutorials as in those that receive lectures. The difference is that the sections doing tutorials only receive short introductory and wrap-up lectures and do the tutorial in between, while in the other sections, the entire time is spent on a lecture.

11.3 Extra Solar Planets (Results)

As with the assessments of instruction on comet-orbits, and likely for the same reasons, that student will show better educational gains when they are actively engaged, (Bransford et al. 2000, Donovan & Bransford, 2005, Hake, 1998, Wandersee et al., 1994, Weimer, 2002) the sections that did the tutorial experienced greater gains on the formative assessment than the sections that received only the lecture on the topic. Table 11.3.1 shows that the tutorial sections' (N=42) score on the visual-assessment rose from 51% to 70%, $g=0.4$, while the lecture sections (N=49) rose to 60%, $g=0.2$.

62% of the tutorial section answered all four parts of item- 1 (the front) correctly compared to 41% of the lecture group.

For question 2 (the back) only 50% of the tutorial sections answered all three questions correctly while 55% of the lecture group did so. Neither group showing much change from the above mentioned diagnostic assessment result of 53%. So while the tutorial shows an advantage over lecture in instruction on the effects of planetary mass and orbital distance on the waveforms (item-1), it does not seem to provide an advantage on the effects of eccentric orbits and multiple-planet systems (item -2), despite the fact that it includes sections about both. Overall, on the formative assessment 38% of the students in the tutorial sections had a perfect score on the visual-assessment compared to 29% in the lecture sections.

As with the comet-orbit visual assessment, a summative assessment was given at the same time as administration of the multiple-choice, whole unit, *Solar System Survey*, one week after the exam on solar system topics. The N=38 students in the tutorial sections remained at 70%, about the level of their formative assessment, but the N=46 students in lecture sections reverted back to near their pre-instruction level of 53%. Again, as with comet-orbits, retention on the summative assessment seems to favor tutorials. Fig. 11.3.1 shows the percentages correct for each group on each assessment.

	% Correct	% Correct	Gain	% Correct
	Diagnostic (N=84)	Formative	g	Summative
Lecture	51	60 (N=49)	0.2	53 (N=46)
Tutorial	51	70 (N=42)	0.4	70 (N=38)
P-Value		0.3854		0.1158

Table 11.3.1 Comparison of percentage scores on the extra-solar planets visual assessment shown in Fig. 10.5.1 on diagnostic, formative and summative assessments in sections taught by lecture and tutorial showing greater gains and retention in the sections taught by tutorial.

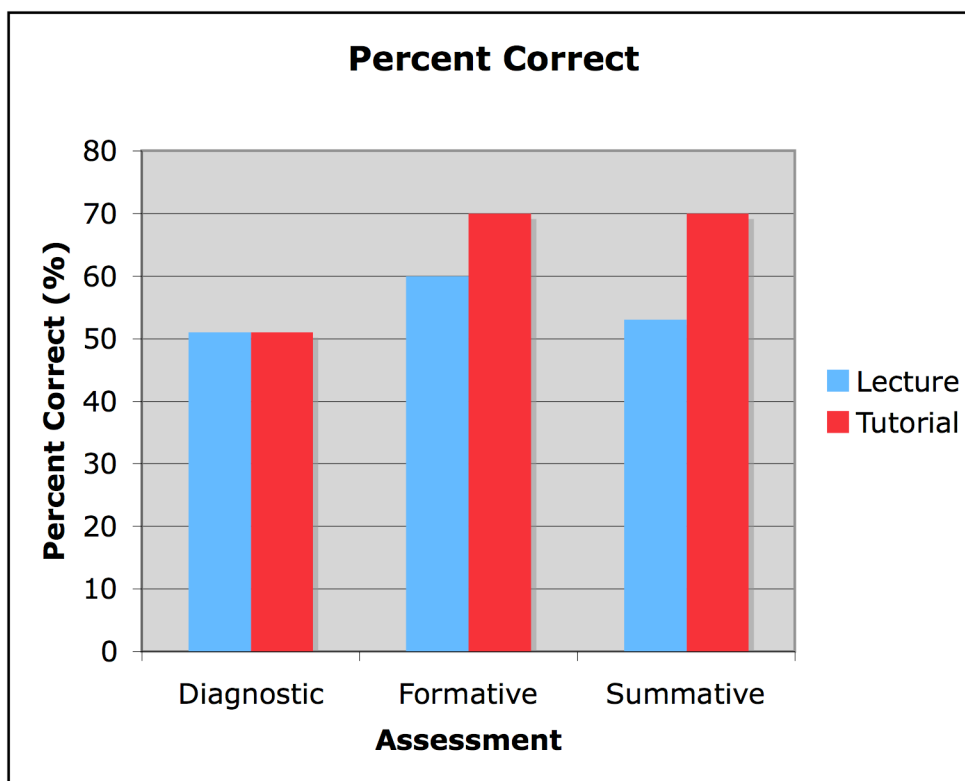


Figure 11.3.1 Percentage of correct responses on the diagnostic, formative and summative extra solar planet visual-assessment for students given a lecture (blue) and doing a tutorial (red) on extra solar planets.

11.4 An Online Tutorial

Students taking an online astronomy laboratory course (ASTR 133 at HFCC) completed a summative assessment (LoPresto, 2009) very similar to the first page of the visual-assessment (Figure 11.2.1). While doing a tutorial about extra solar planets, the students had run an online simulation (<http://www.masteringastronomy.com/>) in which they were able to vary the mass and orbital distance of the unseen planet and observe the resulting variations in the Doppler-shift plots. Students in the course had also previously completed a tutorial on the Doppler-effect. 38 of N=48 students, 79%, matched all four plots correctly with the characteristics of the planet and its orbit. This is higher than the above stated 62% (N=42) of students completing the visual-tutorial and 41% (N=49) receiving a lecture on the topic. This could be partly due to the interactive nature of the simulation, students being able to see the plots change as they vary the planet's parameters, but it is likely not the only reason, as all students taking ASTR 133 are required to be taking ASTR 131 concurrently or to have completed the course previously. This means that they would have had some previous exposure to the topic of extra solar planets. However, the much higher percentage of students matching all of the plots correctly is likely partially due to the effectiveness of the interactive engagement provided by the online simulation.

11.5 HPL Pedagogy

Just as with the *Comets* visual assessment and tutorial in Chapter 10, the purpose of the study during the Winter 2009 semester was to verify the effectiveness of the *Extra Solar Planets* visual tutorial when compared to lectures, with both groups receiving formative assessments. In the Fall 2009 semester, the visual assessment and tutorial were used as part of complete HPL-pedagogy in a comparison with lectures only, with no formative assessments, on the same topic. Results, showing much higher gains, with statistically significant P-values ($P < 0.05$), by the HPL sections when compared to the lecture only sections are shown in Table 11.51 and Figures 11.5.1 and 11.5.2 below.

	% Correct	% Correct	%Correct	Gain	Gain	Chi-Squared test
Item	Pretest (N=141)	Lecture-Only (N=46)	HPL (N=72)	g-lec. only	g-HPL	P-Value
1-Front	25	29	76	0.063	0.69	0.0001
2-Back	46	55	81	0.17	0.67	0.0036
Both Sides	10	23	64	0.15	0.60	0.0001

Table 11.5.1 Percentages of students correctly identifying all 4 waveforms in item-1 (the front) of the extra solar planets visual assessment, all 3 waveforms in item -2 (the back) and those getting both sides completely correct, before and after instruction by lecture-only and by HPL including visual-tutorial during the Fall 2009 semester.

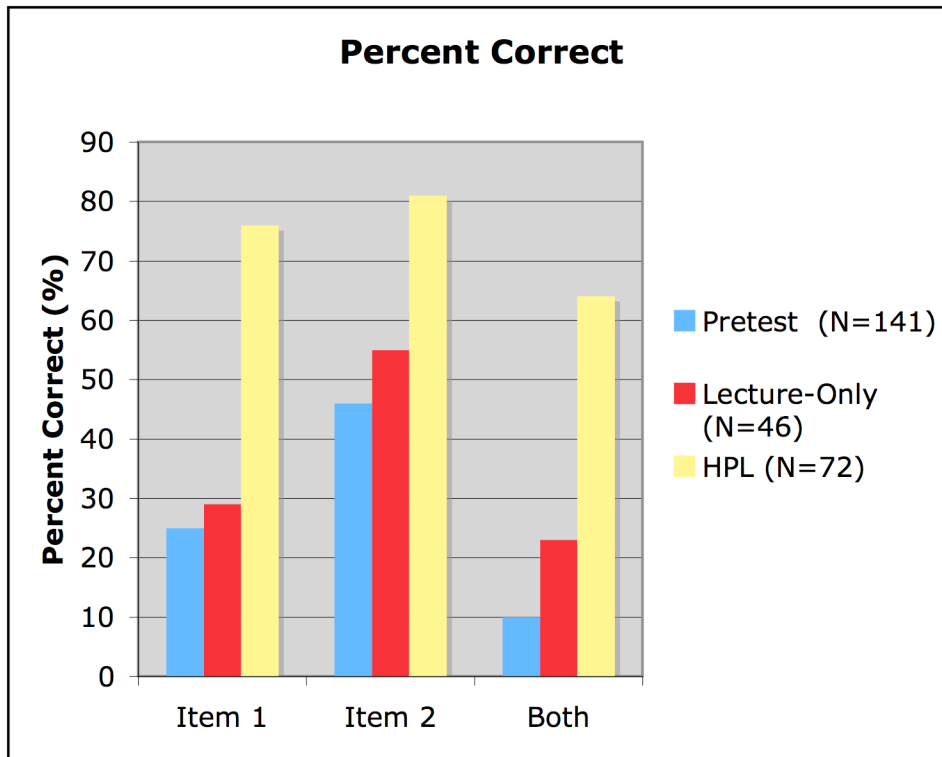


Figure 11.5.1 Percentage of students correctly identifying all the waveforms in item-1, item-2, and in both items on the extra solar planets visual-assessment on the pretest (blue) in lecture-only sections (red) and in HPL/visual- tutorial sections (yellow).

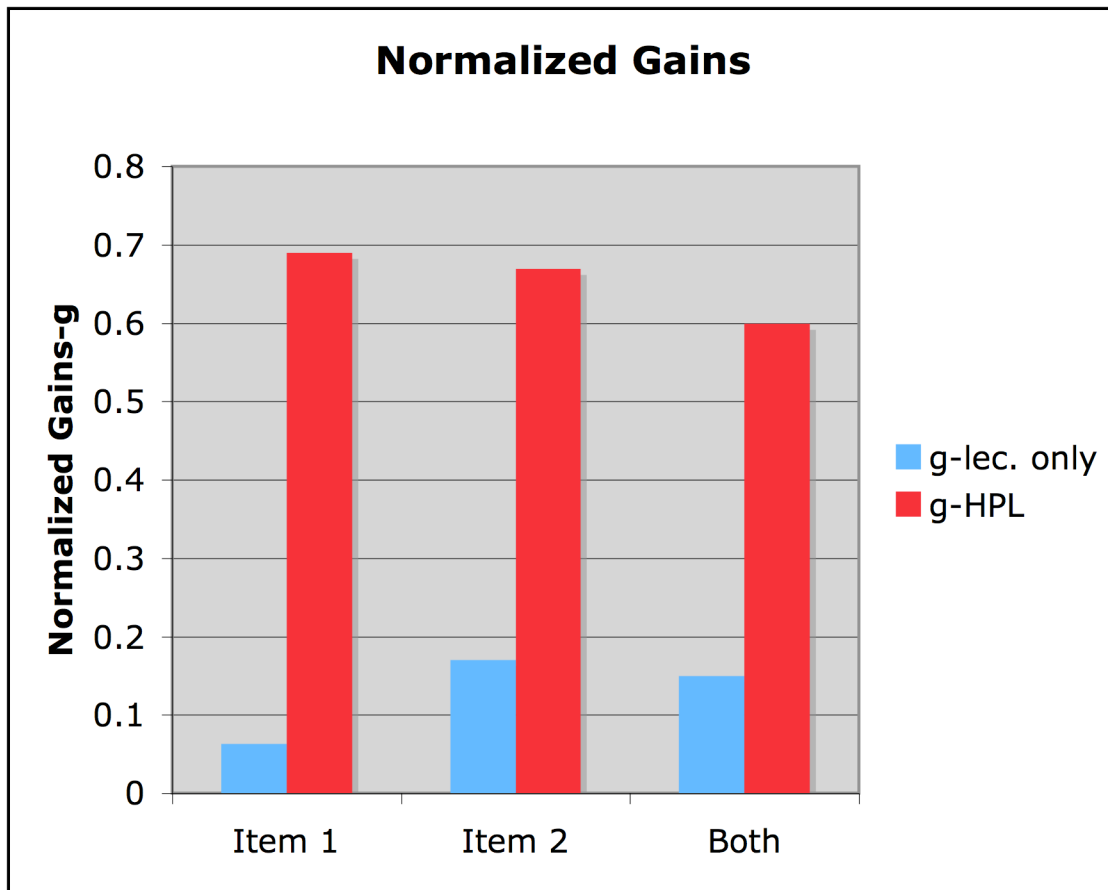


Figure 11.5.2-Normalized gains, g , on both items and the entire extra-solar planets visual assessment for lecture-only sections (blue), and in HPL/ visual-tutorial sections (red).

The coming two are chapters on the development, implementation and assessment of lecture tutorials (LTs). The results of both the effectiveness of the LTs themselves and their use in conjunction with full HPL-Pedagogy will be reported.

11.6 Another Trial

As with the *Comets* visual assessment and tutorial of the previous chapter additional data was collected during the Fall and Winter of the 2010-2011 academic year with the intent of eliminating instructor bias and the Hawthorne effect. (Hake, 1998, from Slavin, 1992) N=143 students in 7 sections taught by 4 different instructors were taught were given the visual assessment shown in Fig. 11.21. N=65 students in 3 of the sections completed the visual tutorial in Appendix 11.1 while N=63 student sin 4 of the sections received lectures on extra solar planets. As with the final trial with the Comets visual assessment and tutorial, none of the sections were taught by the author. The results are shown in Table 11.6.1

	% Correct	% Correct	% Correct	Chi-squared test
	Pretest (N=143)	Lec. (N=63)	Tut. (N=65)	P-value
1-Front	26	32	60	0.0015
2-Back	40	49	66	0.0509
Both Sides	10.5	22	42	0.0234
Score/7	3.4 ± 0.17	4 ± 0.26	5.2 ± 0.23	
% score	48.6 ± 2.4	57 ± 3.7	74 ± 3.3	
gain-g		0.167	0.5	

Table 11.6.1 Percentages of students correctly identifying all 4 waveforms in item-1 of the extra solar planets visual assessment, all 3 waveforms in item-2 and those getting both sides completely correct, before and after instruction by lecture and with the visual-tutorial during the Fall and Winter 2010 and 2011 semesters.

Table 11.6.1 also includes student raw and percentage scores for all seven questions on the visual assessment and normalized gains on the posttest for both the lecture and tutorials groups as well as P-values from chi-squared tests comparing the numbers students giving correct and incorrect responses in both groups. Note that standard errors do not overlap and two of the three P-values are statistically significant ($P < 0.05$) while the other, $P = 0.0509$, is very close

Figure 11.6.1 compares the percentage of students scoring 0-7 on the pretests and on the posttest in the lecture and visual tutorial sections.

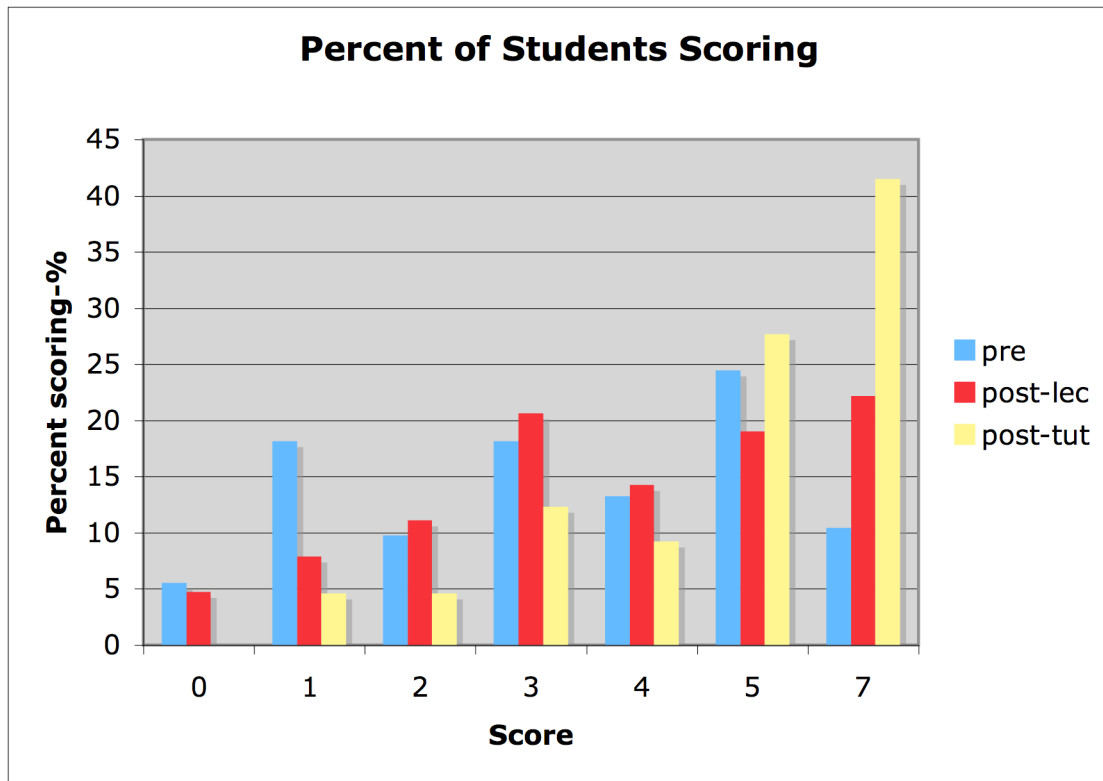


Figure 11.61 Percentage of students scoring 0-7 on the pretest (blue) and on the posttest in the lecture (red) and visual tutorial (yellow) sections.

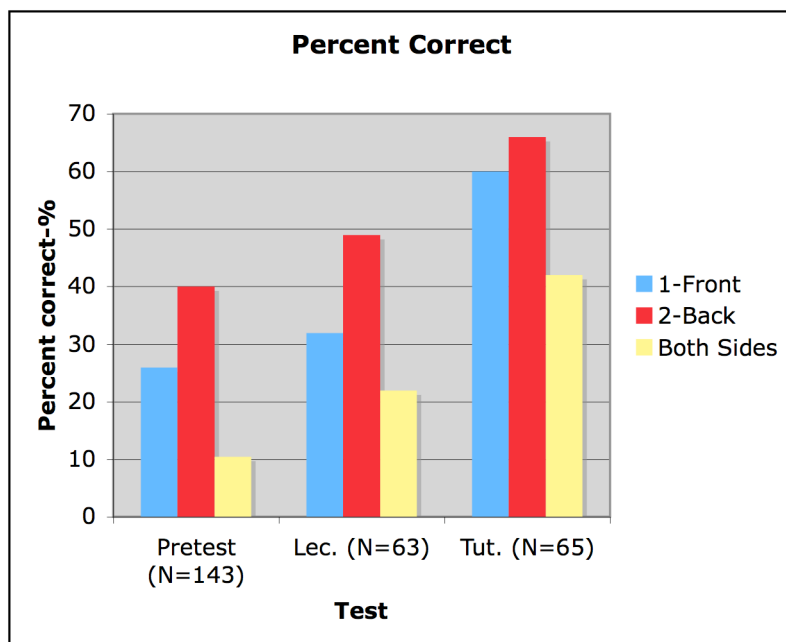


Figure 11.6.2 Data from Table 11.6.2 showing the percent of students answering the entire front side (blue), back side (red) and the entire (yellow) visual assessment on the pretest and in lecture and tutorial sections during the Fall and Winter 2010 and 2011.

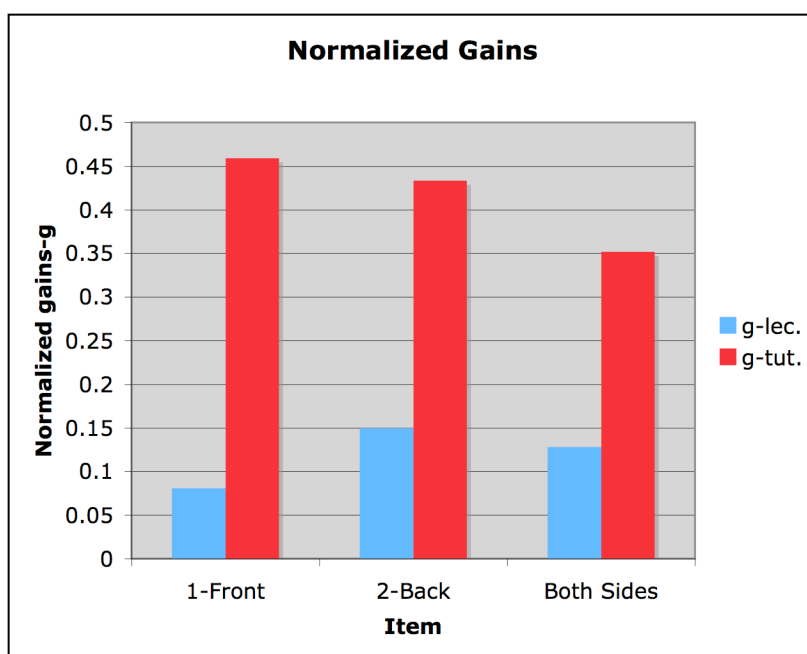


Figure 11.6.3 Data from Table 11.6.1. showing normalized gains on item-1 (front), item-2 (back) and the entire visual assessment in the lecture (blue) and tutorial (red) sections during the Fall and Winter 2010 and 2011.

11.7 Visual Assessments and Tutorials; Promising Tools for Learner-centered Teaching of Astronomy

The results of the studies in both Chapters 10 and 11 show with statistical significance that introductory astronomy students that were taught with visual tutorials had both greater gains and retention than those that received lectures on the same topics. Differences became even more significant when HPL-pedagogy was fully employed. This shows, initially at least, that both visual assessments and tutorials show promise as tools for learner-centered instruction in introductory astronomy.

Chapter 12

Developing, Using and Comparing Lecture- Tutorials to Lectures

12.1 Introduction

As first described in Chapter 5, Lecture-tutorials (LTs) are collaborative learning activities in which, as an alternative to hearing lectures, students attempt to answer a series of questions that build on one another that are meant to help lead them to discover concepts for themselves. LTs have become a popular tool for learner-centered teaching of introductory astronomy courses. (Prather et al., 2007) This and the next chapter will describe of the development, use and assessment of Lecture-Tutorials on two solar system topics, the surface conditions of the Terrestrial planets and solar system formation.

12.2 Developing Lecture Tutorials

The development of a LT begins in a fashion similar to that of planning a lecture; by writing down the important concepts within the topic that the students will need to learn and the facts that support them. It may even be desirable to transcribe into text the lecture that would be given on the topic. The following section is exactly that, the text of a lecture on the surface conditions of Terrestrial planets that is very similar to one given to students in sections that *did not* do the LT developed for the topic.

12.3 Lecture-Surface Conditions of Terrestrial Planets

The Main Idea

The two basic factors that control almost everything that eventually happens on the surface of a terrestrial planet are its *size* and its *distance from the sun*.

Note-the terms *size* and *mass* are of course *not* interchangeable, and the distinction was made in the *Comparative Planetology* activity featured in Chapter 9 but when discussing the terrestrial planets it can be assumed that a planet of *larger size* is also one of *greater mass*.

Size and Mass

The size of a planet will determine much about eventual surface conditions. Terrestrial planets form from solid, mostly rocky and metal material gravitationally pulling together. The energy released by the collisions that occurred during this accretion process heated the material to a molten state from which it has been cooling ever since. Heat from the surface of the planets readily escaped to space, but heat takes much longer to travel through a planet's interior, so the core of a planet remains molten long after the other layers have solidified. This internal heat is most of the energy that fuels geologic activity like volcanism and plate tectonics. Radioactive decay supplies the rest. The larger and more massive the planet, the longer it will take to cool down, so there will be more geologic activity that will last longer.

If a planet is too small, there will not be enough internal heat to drive much if any geological activity. If the planet is more massive, activity may last for a while, but soon stop. On an even more massive planet, geological activity can last for a very long time. The amount, type and duration of geological activity are all important factors in the shaping of a terrestrial planetary surface.

A planet's size will also determine whether or not it has enough gravitational pull to retain an atmosphere. When planets cool from their molten state, they release gases. If a planet is not massive enough, most of the gases will escape to space. More massive planets will gravitationally retain some gases and have thin atmospheres; the most massive planets retain thicker atmospheres. Earth's atmosphere protects our planet's surface from both meteor impacts and harmful radiation from the Sun as well as providing insulation and air to breathe. All of these functions make atmospheric conditions very important in the development of a terrestrial planet's surface.

Distance from the Sun and Temperature

The distance from the Sun directly affects the surface temperature of a planet. The closer the planet is to the Sun, the more solar energy it receives. The surface temperature then in turn has profound effects on the development of the atmosphere. This includes of which gases and in what percentages the atmosphere will ultimately be composed as well as how much erosion, the reworking of the planet surface largely with wind and water, will occur.

Processes that Shape a Planetary Surface

The main processes that affect planetary surface conditions are; impact cratering, geological activity (mainly volcanism and plate tectonics) and erosion. These processes, occur in varying amounts, depending on the size and surface temperature of each terrestrial planet and have transformed their surfaces in different ways, creating the unique individual worlds we observe today.

Mercury and Earth's Moon

Mercury and Earth's moon are the smallest terrestrial objects. The surfaces of both bodies are very similar, covered almost completely by impact craters. All the terrestrial planets were subject to intense bombardment in their early history, but only Mercury and Earth's moon still show the evidence so clearly today. This is precisely because of their smaller size. Neither body is massive enough to sustain much if any geological activity or retain a substantial atmosphere. So neither planet's surface had any atmospheric protection from impact cratering or was reworked by geological activity or erosion.

The fact that Mercury and Earth's moon are so similar in appearance proves that among the smaller objects (those too small to retain an atmosphere) that their small size is the main factor that controls surface conditions and that this factor is much more important than their distance from the Sun. Mercury is much closer to the Sun than Earth's moon and therefore has a much higher surface temperature, yet the surfaces of the two objects appear much the same. Since the two objects have similar size, but are at different

distances from the Sun, their size must be the factor that controls their surface conditions. This is also true for many of the outer solar system moons, those of the Jovian planets that range in size between that of Mercury and Earth's Moon. They are all much farther away from the Sun and therefore receive much less solar energy and have much colder surfaces temperatures, but their cratered-appearance is much like that of Mercury or Earth's moon, so again, size must be the common factor.

Also due to their lack of atmospheres, both Mercury and Earth's moon experience wide variations in day and night time temperatures. Atmospheres act as insulation, keeping a planet from getting too hot during the day and too cold at night. Being so close to the sun, it is no surprise that Mercury is very hot during the day, as high as 620 K, but at night it cools down to almost 100K. Earth's moon, being further from the sun does not get as hot its temperatures vary from about 400K during the day to also near 100 K at night.

Planetary Geology

Earth

Earth is still geologically active. Volcanic eruptions and tectonic shifting are occurring regularly, constantly rearranging the planet surface.

Venus

Venus is similar to Earth in size and mass, so it should be or have been nearly as geologically active as Earth. However, this is more difficult to determine since Venus is completely covered with clouds all the time. Radar images taken by the *Magellan* spacecraft show evidence of volcanic features and impact craters but no tectonics. Although it is still difficult to tell for sure, because the cloud cover makes it impossible to continually observe the surface, Venus may no longer be geologically active. Being slightly smaller than Earth, the internal heating may no longer be sufficient to sustain the activity. A possible reason for Venus not having tectonics is that the intense heat may have made the crust more pliable and less brittle than on Earth so that it did not break into individual plates.

Mars

Mars is smaller and less massive than Earth or Venus, so it has not been geologically active for a long time. There is, however, evidence that both volcanism and tectonics occurred there in grand fashion in the past. There are giant volcanic mountains including Mt. Olympus (*Olympus Mons* in Latin) that is as large as the entire state of Arizona and three times as tall as Mt. Everest. Due to surface gravity less than 40% of that on Earth, mountains on Mars can grow much higher. Mars also has a grand canyon; Earth's Grand Canyon (in Arizona) was carved out of the landscape by erosion from the flow of the Colorado River. Mars' grand canyon, called the Valley of the *Mariner* Spacecraft (*Valles Marinaris* in Latin) is named after the spacecraft that gave us our first close look at it, is a rift valley, a gigantic gap along a geologic fault, the boundary between two tectonic plates that have moved apart. It is as long as the entire United States and much deeper than Earth's Grand Canyon.

Planetary Atmospheres

Volcanic Degassing

After rock and metal first condensed out of the solar nebula, gravitation between the objects began to pull them together to form larger bodies, which then also began to gravitationally pull together. The collisions between the larger objects generated much energy and heated the forming planets until their material became molten. As they eventually cooled, they released gases that became the initial atmospheres of the terrestrial planets. This process, called volcanic degassing, can be observed when lava from volcanic eruptions on Earth cools. The gases released are water vapor, carbon dioxide and nitrogen.

Smaller Bodies

Mercury and Earth's moon are too small and therefore not massive enough to retain the gases, so the gases escaped to space leaving these objects without atmospheric protection from impacts or erosion to erase the craters and thus showing the evidence of this ancient bombardment that we see today.

Larger Bodies

Earth, Venus and Mars are large enough and therefore massive enough, that they did have the gravitational pull necessary to retain their initial atmospheres. The atmospheres they have today have been shaped by chains of events that were begun by their initial surface temperatures, which were set by their differing distances from the Sun.

Earth

Earth's surface temperatures cooled so that most of the water-vapor condensed into liquid, filling up the lower elevation basins and creating the oceans that cover almost three-fourths of the planet today. Liquid water absorbs carbon dioxide; so much of the carbon dioxide was also taken out of the atmosphere leaving nitrogen as the most abundant gas. Today, Earth's atmosphere is about 78% nitrogen and 21% oxygen with the other 1% being traces of other gases including what was left of the water vapor and carbon dioxide.

The next question that must be asked is where the oxygen, which is unique among the Terrestrial planets to Earth's atmospheres, came from? The answer is that the abundance of liquid water made Earth a hospitable environment for life to develop, specifically plants. In their respiratory process, photosynthesis, plants absorb sunlight, take in carbon dioxide and expel oxygen. This even further reduced the atmospheric concentration of carbon dioxide and introduced the oxygen necessary for the development of animal life including eventually, human beings.

The Greenhouse effect

The greenhouse effect is the process by which a planet heats its atmosphere. Because of its high temperature, the Sun emits shortwave, high-energy radiation that easily penetrates an atmosphere then is absorbed by the planet. Being at a much lower temperature, the planet reemits much longer wave, low-energy radiation, some of which is then absorbed by atmospheric gases. The absorbing gases are known as the “greenhouse gases,” water vapor and carbon dioxide being chief among them. A good example of the greenhouse effect is what happens in a car parked outside on a hot day. Energy from the sun passes through the windows, but after it is absorbed and reemitted by the lower temperature interior of the car, much of it cannot escape and the interior of the car becomes very hot.

The greenhouse effects heats Earth’s atmosphere only moderately. This is because most of the initial atmospheric water vapor on Earth cooled and condensed to liquid that in turn absorbed much of the initial carbon dioxide. The water also gave rise to plants that removed even more carbon dioxide from the atmosphere through photosynthesis

Venus

The history and therefore the conditions of the atmosphere of Venus are far different. Surface temperatures never cooled enough for water vapor to condense, so no carbon dioxide was absorbed. The two greenhouse-gases absorbed tremendous amounts of heat resulting in a runaway greenhouse effect that left Venus the way it is today. The atmosphere is mostly carbon dioxide with atmospheric pressure, the weight of the atmospheric gases pushing down on the planet surface, over 90 times of that found on Earth. Despite having a similar mass and therefore a similar gravitational pull, a large part of the reason that Venus’s atmosphere is so much thicker than Earth’s is because of the fact that little or none of the original carbon dioxide was removed as it was on Earth. Carbon dioxide is a much heavier gas than the combination of oxygen and nitrogen that makes up Earth’s atmosphere.

Surface temperatures on Venus are as high as 750 K, hotter than Mercury, day and night, and droplets of sulfuric acid condense out of the atmosphere, much the way water does on Earth. The dew on Venus is acid. Water vapor is much lighter gas than carbon dioxide, so most of the original water vapor rose as the heavier carbon dioxide sunk to the surface. Much of the water vapor escaped to space and some of it condensed into the thick cloud cover we always see around Venus.

Too Hot, Too Cold, Just Right

Venus is an example of how an atmosphere can end up if it is subject to too much greenhouse effect. This suggests that it could be used as an example of the dangers of global warming. Global warming is an enhancement of the greenhouse effect that is occurring on Earth due to extra carbon dioxide being emitted into the atmosphere through pollution. Although scientific studies overwhelmingly show that global warming is a real environmental problem that human beings need to deal with, clearly, the current atmospheric conditions on Venus were caused by an evolutionary process that was result of the initial conditions being slight different than those on Earth. Venus is similar to Earth in mass and size and proximity to Sun so it had the potential to develop surface conditions much like those on Earth, but being just a little closer to the sun and thus not cooling off enough for its water vapor to condense into liquid, resulted in a chain of events that that resulted in the much different surface conditions than Earth we currently find on Venus.

If Venus is an example of what too much greenhouse effect can do, Mars provides an example of conditions when there is too little greenhouse warming. Being farther from the sun than Earth, most of the water vapor ended up frozen into ice. Being much smaller and much less massive than Earth or Venus, Mars did not have enough gravitational pull to retain nearly as thick of an atmosphere as either of its Terrestrial cousins. Today we find Mars with a mostly carbon dioxide atmosphere that is as much thinner than Earth's as

Venus' is thicker. The combination of being farther from sun than Earth and therefore getting less energy to start with and very little greenhouse warming occurring in the thin air leaves even the warmest places on Mars at their warmest times of year, still very cold.

12.4 Listing the Important Concepts and Supporting Facts

From such a lecture, a list of the important concepts and supporting facts that will need to be included in the LT can now be extracted;

Concepts and Facts-Surface Conditions of Terrestrial Planets

Processes that shape the surfaces of Terrestrial planets are;
<i>cratering, volcanism, tectonics and erosion</i>

Cratering will affect all surfaces;
Volcanism, tectonics and erosion can “erase” cratering

Whether or not volcanism and tectonics (<i>geological activity</i>) will occur and how long it will last depends on the size and mass of a planet;
Earth is currently geologically active
Venus shows evidence of past geological activity but observations are unclear as to whether it is still active
Mars shows evidence of past geological activity but observations show that is currently geologically dead
Mercury and Earth's moon show little evidence of substantial geological activity at any time

Whether or not a planet will retain an atmosphere and experience erosion and how thick the atmosphere will be depends largely on if planet has enough gravitational pull and thus the size and mass of a planet;
Venus and Earth have substantial atmospheres.
Venus' atmosphere is much thicker than Earth's .
Mars has a thin atmosphere
Mercury and Earth's moon have little or no atmosphere

Mercury and Earth's moon are covered with craters;
Neither is massive enough for substantial or lasting geological activity
Neither is massive enough to retain atmospheres to protect them from meteor bombardment
No geology or erosion "reworked" either surface to hide craters

Initial atmosphere of Terrestrial planets created by volcanic degassing when the planet is cooling were composed of;
<i>Nitrogen, Carbon Dioxide and Water Vapor</i>

Earth and Venus are of similar size and mass;
<i>On Venus;</i>
Being closer to the sun, the slightly higher temperatures did not allow water vapor to condense into oceans
The high content of water vapor and carbon dioxide resulted in a runaway <i>greenhouse effect</i> and very high temperatures on Venus

<i>On Earth:</i>
Water could condense and form oceans
Oceans absorbed much of the carbon dioxide
Oceans gave rise to plants.
Plants absorbed even more carbon dioxide
Plants introduced oxygen to the atmosphere
Due to the Presence of oceans and only traces of water vapor and carbon dioxide resulted in a moderate greenhouse effect

Mars is farther from the sun and smaller and less massive
Mars received less solar energy.
Mars retained a much thinner atmosphere
Many of the gases froze in to ice
Much less greenhouse effect, very low surface temperatures

12.5 Writing the Questions

Now, taking an important concept on the list such as;

Whether or not a planet will retain an atmosphere depends on whether or not the planet has enough gravitational pull, which depends the mass of a planet.

The next step is writing a question that leads the students to discover the important concepts that have been identified. The questions should be short and about single concepts. Each new question should build on the answers to the previous ones. The necessary facts can be provided in the questions or in the form of data tables or figures that the students are instructed to examine. Rather than just telling the students the following facts;

Venus and Earth have substantial atmospheres.

Venus' atmosphere is much thicker than Earth's .

Mars has a thin atmosphere

Mercury and Earth's moon have little or no atmosphere

they can be included in a data table;

Table 12.5.1 Planetary Atmospheric Data

Planet	Surface Temperature	Atmospheric Composition	Atmospheric Pressure
Mercury	100-620 K (night-day)	none	0 (none)
Venus	750K	96% CO ₂ ; 3.5% N ₂	90 (very thick)
Earth	300K	78% N ₂ ; 21% O ₂	1 (thick)
Earth's Moon	100-400 K (night-day)	none	0 (none)
Mars	218K	95% CO ₂ ; 2.7% N ₂	1/90 (thin)

that students are instructed to use to answer the question;

Which factor is most likely responsible for the pressure (or thickness) of an atmosphere or, whether or not a planet even has an atmosphere? Hint-Gravity is what holds atmospheric gases around the surface of a planet.

Distance from the Sun / Size of Planet (circle one)

Another question for which they can be directed to the same table is;

Which factor likely has the most effect on the surface temperature of a planet?

Distance from the Sun / Size of Planet (circle one)

Note that the facts or data are not presented to be memorized, but, as recommended in an HPL-Knowledge-centered learning environment, they are used to aid in the understanding of a concept.

Another example focusing on planetary geology, the important concept is;

Whether or not geological activity will occur and how long it will last depends on the size and mass of a planet.

Instead of just being told the following facts;

Earth is currently geologically active

If not active, Venus's geological activity has stopped only recently

Mars shows evidence of past geological activity, but is currently geologically dead

Mercury and Earth's moon show little evidence of substantial geological activity at any time

Students can be shown pictures of the planetary surfaces and asked to fill-out the following table (or the information could be provided in the table);

Table 12.5.2 Processes affecting the surface of Terrestrial Planets

Process	Mercury	Venus	Earth	Moon	Mars
Cratering (from impacts)				yes	
Geology (tectonics & volcanism)				no	
Erosion (wind & weather)				no	

Then asked the questions;

Based on the data collected from the pictures you examined, what seems to be the relationship between the size of a planet and whether or not there is geological activity (tectonics and volcanism)?

Also based on your data; does the distance from the sun (and therefore the surface temperature) seem correlated with geological activity?

After answering questions based on collecting and examination of data, students can then be lead to drawing conclusions from their data with more complex questions, such as;

The surfaces of the Moon and Mercury are very similar; they are covered with many impact craters and have few other surface features.

This suggests that size / surface temperature (circle one)

is a more important factor in determining whether or not a planet will have geological processes occur. Explain your choice.

The eventual goal is that through this learner-centered process of guided inquiry, similar in fashion to actual scientific investigation (Donovan & Bransford, 2005) students, having worked with and learned the material themselves, will have constructed their own model. This will enable them to come away with a better understanding of the important concepts than if they were simply told (lectured to) about the topic. (Weimer, 2002)

The exact fashion in which this LT and the one that will be described in Chapter 13 were used in the classroom is described in detail Chapter 5 and is similar to the guidelines for their use. (Prather et al., 2005, Slater, 2008: see Pasachoff et al., Prather & Brissenden, 2009, *Lecture Tutorials*)

The final step in the development of a LT occurs during the first few uses, revision. Revisions should be based on observing and recording problems that arise during classroom use. Some examples; a question is not worded clearly, too much is being asked in one question, the answer to a question requires information that has not yet been presented, not presented clearly or in enough detail or the entire tutorial is too long. The versions of the LT *Surface Conditions of Terrestrial Planets* from which the above examples came, has been revised several times over multiple semesters and split into two parts shown below; 1- *Planetary Geology* and 2-*Planetary Atmospheres*. Both parts of the LT are found in *Appendix 12.1*.

12.6 Comparing Lecture Tutorials with Traditional Lectures

After revision, the LT *Surface Conditions of Terrestrial Planets* was used in two, thirty-student, sections of introductory astronomy, each taught by a different instructor. As in the studies in described in previous chapters, having different instructors teaching the topic by both methods is meant to minimize any instructor-related bias in the data. Each instructor also taught the topics in a more traditional lecture format to one other section by giving a lecture on the topic similar to the one transcribed above.

As outlined in Chapter 5, students in the sections doing the LT, received only a brief introductory lecture on the main ideas before the LT was done and a short wrap-up after the LT was finished. The ideas that the size and mass and temperature, caused by the distance from the sun, are the main factors that control the evolution of a planetary surfaces and the process that affect the surfaces were introduced, but no details on the development of individual planets were discussed.

As a pretest prior to any instruction or reading on any solar system topic the N=100 students in all section were given a 25-item *Solar System Survey*. The survey was developed for this project to assess the effectiveness of this and the other tutorials on solar system topics (Chapter 14).

At the beginning of the next class period, after the topics were taught by LT or by lecture in the respective sections, students in all sections were given the questions pertaining to the subject of the LT as formative assessments in a classroom-response/“clicker” format.

12.7 Results

A week after the exam on the solar system, about two weeks after coverage of the Terrestrial planets, the assessment questions were given a third time, again as part of the same 25-item *Solar System Survey*, as a posttest. Table 12.7.1 and Figures 12.7.1 and 12.7.2, compare scores on the following ten items from the assessment about Terrestrial planet surface conditions before and after instruction and gains in sections doing the LT to those receiving lectures.

1. Which process(es) is (are) involved in shaping the surface of a terrestrial planet?
 - a. Cratering
 - b. Tectonics
 - c. Volcanism
 - d. Erosion
 - e. [All of the above]

2. Which factor(s) is (are) important in determining the amount and duration of geological activity on a terrestrial planet?
 - a. Distance from the sun
 - b. Surface temperature
 - c. Size of the planet
 - d. [Both a and b above]
 - e. [All of the above]

3. Which factor(s) is (are) important in determining whether or not a terrestrial planet has an atmosphere and the conditions (composition, thickness etc.) of the atmosphere?
- a. Distance from the sun
 - b. Surface temperature
 - c. Size of the planet
 - d. [Both a and b above]
 - e. [All the above]
4. Which is a correct list of the terrestrial planets in order of increasing atmospheric pressure (from the thinnest to the thickest atmosphere).
- a. Mercury, Venus, Earth, Mars
 - b. Venus, Mercury, Earth, Mars
 - c. Earth, Venus, Mars, Mercury
 - d. Mercury, Mars, Earth, Venus
 - e. Mars, Earth, Venus, Mercury
5. Which is NOT a reason that the dominant surface feature on Mercury is impact craters.
- a. Smaller size
 - b. Lack of geological activity
 - c. Lack of an atmosphere
 - d. Close proximity to the sun
 - e. [All of the above ARE reasons]

6. The fact that Mercury and the Moon appear so similar suggests that which factor was the most important in the shaping of their surfaces?

- a. size
- b. distance from the sun
- c. temperature
- d. [All of the above]
- e. [None of the above]

7. Which is NOT a reason related to why it is so much colder on Mars than Earth?

- a. Mars is smaller than Earth
- b. A current lack of geological activity on Mars.
- c. Mars' atmosphere is very thin.
- d. Mars is farther from the Sun than Earth
- e. [All of the above ARE reasons]

8. Which is the main reason that atmospheric conditions on Earth and Venus turned out so different?

- a. Venus is just a little larger size than Earth
- b. Venus is no longer geologically active
- c. Venus has a greenhouse effect
- d. Venus is closer to the sun than Earth
- e. [All of the above ARE reasons]

9. Which planet has the most evolved (changed) atmosphere since the time of its formation?

- a. Mercury
- b. Venus
- c. Earth
- d. Mars
- e. [All of the above have evolved about the same amount]

10. Which is NOT true about Jovian (outer solar system) moons?

- a. They can be as large as Earth's moon or even Mercury.
- b. They are unlikely to be geologically active or to retain an atmosphere due to their relatively small size,
- c. They are unlikely to be geologically active or to retain an atmosphere due to how far from the sun they are.
- d. Some have been discovered to be geologically active and with atmospheres, but both are unusual.
- e. [All of the above are true]

	% Correct	% Correct	% Correct	Gain	Gain
Item#	Pretest N=100	Posttest (Lecture) N=46	Posttest (Tutorial) N=38	g-lec.	g-tut.
1	66	76	84	0.30	0.54
2	12	43	42	0.36	0.34
3	24	26	29	0.03	0.07
4	20	57	58	0.46	0.47
5	14	33	37	0.22	0.27
6	33	41	53	0.12	0.29
7	16	24	29	0.09	0.15
8	28	28	42	0.00	0.20
9	61	57	74	-0.12	0.33
10	24	28	42	0.06	0.24
Average	29.8	41.3	49.0	0.15	0.29
Standard Error	±6.0	±5.4	±5.8	±0.06	±0.04

Table 12.7.1 Pre and Posttest scores and normalized gains (Hake, 1998) for students receiving lectures and doing the *LT Surface Conditions of Terrestrial Planets*. Note that the standard errors for the average percentage scores barely overlap and those for the average of normalized gains do not at all.

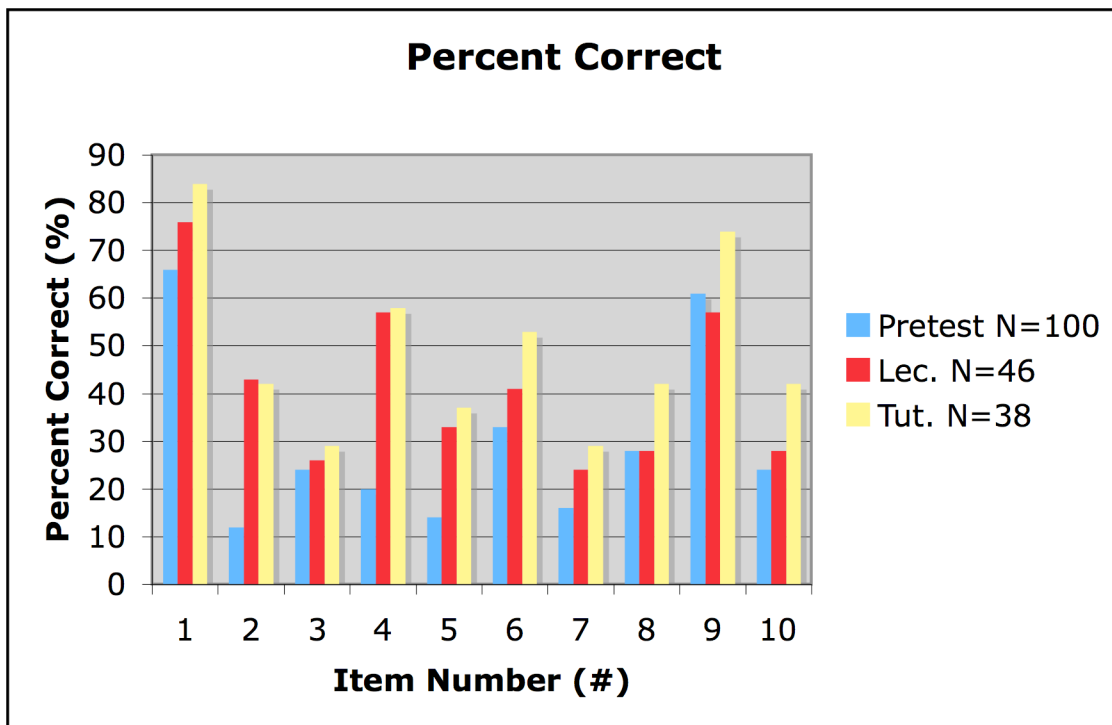


Figure 12.7.1-Percent of correct responses before (blue) and after instruction on assessment questions on terrestrial planet surface conditions in sections receiving lecture (red) and doing the LT (yellow).

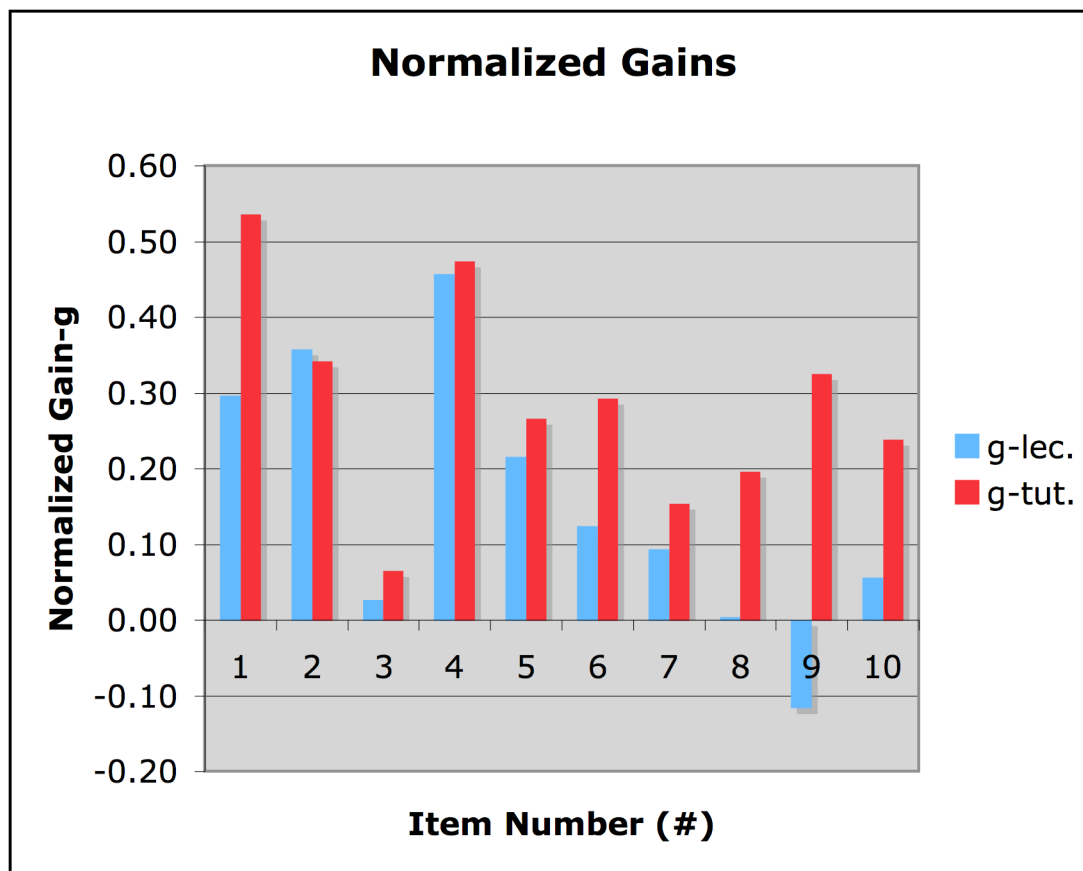


Figure 12.7.2-Normalized gains (Hake, 1998) on each item in the assessment of Terrestrial planet surface conditions in lecture (blue) and LT (red) sections.

As can be seen in Table 12.7.2, students in the tutorial sections had a an average posttest score that was higher than students in the lecture sections by more than the standard error. The normalized gains students doing the LT were nearly twice as high with no overlap in the standard error.

Inspection of Figures 12.7.1 and 12.7.2 show that the tutorial sections had larger gains than the lecture sections on more than half the items and gains were at least comparable to those of the lecture sections on all items. It can be difficult to know exactly why the gains of the two groups on one specific item will be similar and then much different on another, but items 6, 8 and 9, all of which the tutorial showed large advantage over lecture, were based on applying the knowledge of how factors affect surface conditions where items 2 and 3 in which both groups had similar gains were simply about what the

factors were. This suggests that having worked through the processes of each of the planets geological and atmospheric development with the LT was indeed an advantage. This is yet another example of a knowledge-centered learning environment, showing that better understanding of why something is the way it can lead to better retention of facts than rote memorization.

The LT students also had much higher gains than the lecture students on item-10 involving a prediction about the surface conditions of Jovian moons. Having students make predictions based on what they have previously learned is a good way for them to put their knowledge to use and test their understanding. (Bransford et al., 2000) The third of the *review questions* at the end of the LT asks students to make a prediction about the surface conditions of the Jovian moons based on what they have learned about the surface condition of terrestrial planets. Item 6 in the assessment, on which, as discussed above, the LT students also had higher gains, asks whether the size of the objects or distance from the Sun was more important in shaping the similar surface conditions on Mercury and Earth's moon. The variable that is similar is, of course, size, since they are different distances from the Sun, so size must be more important. If students recognize this, the fact that the largest Jovian moons are similar in size to Mercury should lead to a prediction that, based on this, most Jovian moons should have very little if any atmosphere or geological activity and if they do, there must be some other explanation. This result suggests that working the LT may have indeed led to students making a better prediction than those hearing lectures.

The students' predictions are tested in the next class period when they view a video about the Jovian planets and their moons guided by a worksheet that goes with the video in which they are again asked to make a prediction similar to the one above.

12.8 Employing HPL Pedagogy

As with the activities described in the previous two chapters, data taken in Winter 2009 was used for comparison of instruction with the LT to instruction by lecture, with both groups undergoing the same assessments, including formative assessment during instruction. Also as with the previous activities data taken in Fall 2009 was used to compare gains from instruction with the LT when *used as part of HPL-pedagogy* to gains from instruction by lecture-only. The main difference other than LT vs. lecture, being that sections doing the LT also underwent formative assessment in a classroom response/"clicker" format while the lecture only sections did not.

As a result of the removal of formative assessments (Wilson & Sloane, 2000) from the lecture-sections and specifically those in the "clicker" format that has proven to be so effective, (Duncan, 2007, Mazur, 2007) it should be expected that the difference in overall gains and those on specific items between the two groups would increase.

Table 12.8 .1 and Figures 12.8.1 and 12.8.2 show the results that were expected, sections taught with HPL pedagogy out gained the lecture-only sections on all 10 items and the difference in the average gains and normalized gains between the two groups were larger than in the previous semester when the LT was being tested with no overlap in standard error. When differences in gains are this large it is considered likely due largely to the differences in instructional method and not only from more exposure to the assessment. (Prather et al., 2005, Bailey, 2008, Prather, 2008)

	% Correct	% Correct	% Correct	Gain	Gain
Item #	Pretest N=144	Posttest (Lec.-only) N=49	Posttest (HPL) N=72	g-lec.-only	g-HPL
1	65	69	92	0.14	0.77
2	8	20	44	0.14	0.40
3	30	22	42	-0.11	0.17
4	17	41	78	0.28	0.73
5	15	29	38	0.16	0.26
6	28	27	65	-0.03	0.52
7	17	8	25	-0.11	0.09
8	28	20	39	-0.10	0.15
9	53	71	82	0.40	0.62
10	21	22	36	0.02	0.19
Average	24.1	32.9	54.1	0.08	0.39
Standard Error	±4.1	±6.7	±7.3	± 0.05	±0.08

Table 12.8.1- Pre and Post-test scores and normalized gains (Hake, 1998) for students instructed by lectures-only and instructed with the LT- *Surface Conditions of Terrestrial Planets* as part of HPL pedagogy. Again note that standard errors for average percentage score and normalized gains do not overlap.

It should be noted that the pretest scores in Winter 2009, Table 12.7.1, 29.8 ± 6.0 are higher than those in Fall 2009, Table 12.8.1, 24.1 ± 4.1 . The standard errors do overlap, but both scores do not lie within the other's error bars. These numbers should be more consistent and there is not a satisfactory explanation for the discrepancy between pretest scores during the two semesters. This could call in to questions the comparison of the gains during the two semesters, but perhaps not as much so during each individual semester.

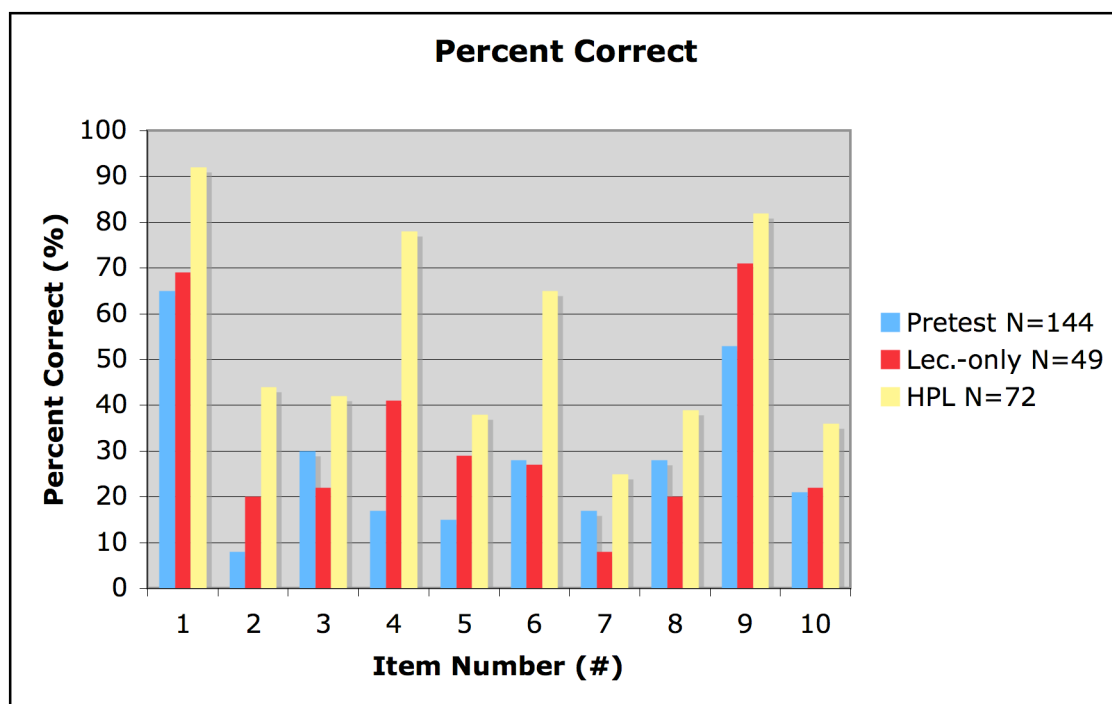


Figure 12.8.1 Percent of correct responses on each item in the assessment of Terrestrial Planet surface conditions on the Pretest (blue) in lecture-only (red) sections and HPL (yellow) sections.

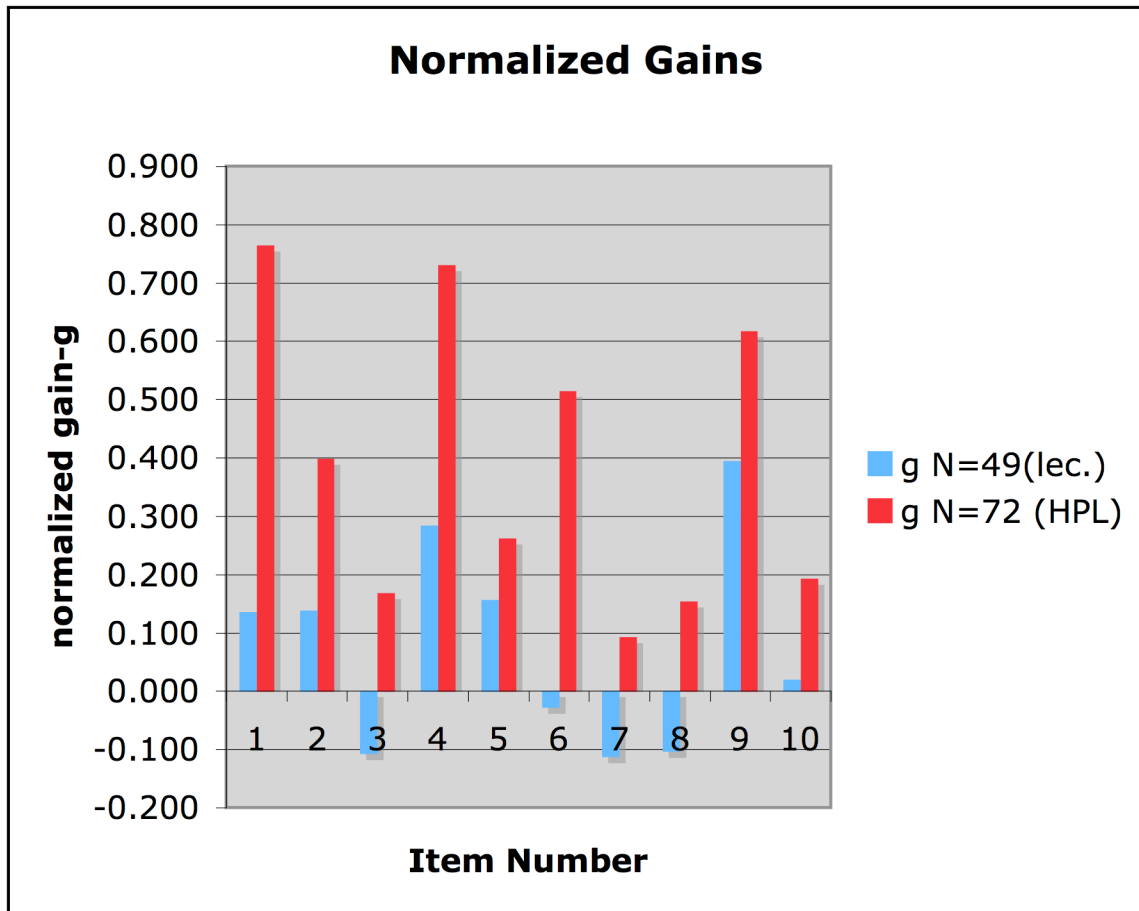


Figure 12.8.2 Normalized gains (Hake, 1998) on each item in the assessment of Terrestrial Planet surface conditions in lecture-only (blue) sections and HPL (red) sections.

Chapter 13

A Lecture Tutorial on the Formation of the Solar System

13.1 Introduction

Another lecture-tutorial designed for this study was on the formation of the solar system. As per the schedule in Chapter 6, this activity is the main focus of the second day of solar system instruction placed between the *Comparative Planetology* activity featured in Chapter 9 and the *visual-tutorial* on extra solar planets in Chapter 10. It was created, implemented, revised and tested in the same manner as LT in the previous chapter on terrestrial planetary surfaces.

13.2 The Lecture

The following is a transcription of a lecture very similar to that given to the students in the sections that were *not* going to be doing the LT on solar system formation. The lecture covers all the important points in the process of planetary formation.

The Formation of the Solar System

Our Sun was formed by a gravitational collapse within a gigantic cloud of mostly hydrogen gas and dust in the otherwise nearly empty *interstellar* space between stars in our galaxy. The leftover material surrounding this not-yet shining *protosun* was called the *solar nebula*. Eventually, the protosun accumulated enough material from the nebula that it became massive enough to put enough pressure on its core to raise temperatures there to the point where nuclear fusion began to occur. This process provided the energy necessary for the Sun to give off light and heat, to shine and thus become a star. This process will be covered in much more detail at later time when stars are being studied.

The material in the solar nebula, what is leftover from the formation of the Sun, would become the material from which the planets of our solar system would form. Initially, temperatures were so hot that most of the solar nebula remained gaseous, but as the solar nebula cooled, temperature reached a point where rocks and metals began to condense

out of the nebula. Too close to the Sun temperatures never cooled enough for this to happen so no planets could form there. Beyond about 0.3 AU the solid rock and metal could begin gravitationally pulling together, first forming small rocky-metal objects called *planetisimals* and then larger *protoplanets*.

Within about 5 AU of the sun, temperatures remained high enough so that no other materials could condense out of the nebula and also due to these higher temperatures, the gas molecules were moving very fast. This left the small rocky-metal *protoplanets* unable to gravitationally capture appreciable amounts of these gases. The *protoplanets* continued to accumulate more of the rock and metal in their orbits and eventually became what are now known as the Earth-like or small, low-mass, high-density (rock-metal) terrestrial planets that are found closer to the sun.

Beyond 5 AU, temperatures cooled enough for water, methane and ammonia to condense from the solar nebula and form layers of ice on the rocky-metal objects. This increase in the mass of the objects gave them stronger gravitational pull than the lighter objects closer to the Sun. Their greater gravitational pull combined with the cooler temperatures in these further-out regions of the solar nebula slowing down the motions of the gas particles allowed the objects to collect large amounts of the gases and grow to tremendous size. They became much more massive than their rock-metal cousins nearer to the Sun and are now known as the Jupiter-like, or large, massive, low density (gas and liquid), Jovian planets.

High pressures from the large amounts of gas above the icy layers, likely heated up and melted the ice, leaving the basic structure of a Jovian planet, a terrestrial-planet sized rocky-metal core, surrounded by a large liquid ocean below a huge, thick atmosphere of mostly hydrogen and helium gas. The formation of these three-layered Jovian planets was a three-step process. The terrestrial planets were basically formed in one step, so are considered less evolved than their giant liquid and gas Jovian planets.

Some of the *planetisimals* and even *protoplanets* did not become part of a Terrestrial or Jovian planet. Some were gravitationally captured, mostly by the more massive Jovian planets and became moons. Other small rocky objects of the inner solar system are now called *asteroids*. Many of the asteroids are concentrated in an *asteroid belt* between the orbits of Mars and Jupiter. The material in this belt was never able to pull-together and form a planet due to the gravitational influences of Jupiter. Mars' two small moons were likely captured from the asteroid belt. Small rocky objects of the cold outer solar system were covered by condensing ice and are now known as *comets*. A large group of comet-like objects, called the Kuiper-belt, lies beyond the orbit of Neptune. A few of Neptune's moons may have been captured from this population. Neptune's orbit is crossed by the orbit of the most well known member of the Kuiper-belt, the *dwarf-planet* Pluto.

During the formation of the solar system, when there were more objects that had not yet become parts of planetary systems, many collisions occurred. Earth's moon is believed to have been formed by a collision with a large object. A collision is also believed to be the reason that Uranus' rotational axis lies nearly in the plane of its orbit rather than more "up and down," or perpendicular relative to it, like the other planets. Objects that are likely to impact other objects are called *meteoroids*, the holes left after collisions are called *impact-craters*. There are many impact-craters on the surfaces of the terrestrial planets and their moons and Jovian moons from meteor collisions. As collisions occur, over time the number of objects "available" for further collisions becomes less and less. Most impact-craters, like we see on our Moon, were formed long ago, but there are still occasional large-impacts like the Tunguska event on Earth about a century ago or the collision of a comet with Jupiter in 1994.

13.3 Listing Important Concepts and Supporting Facts

Now the important concepts and facts to support them can be extracted and listed.

Concepts and Facts-The Formation of the Solar System

Planets form from the leftovers of star formation-the <i>solar nebula</i>
--

Distance from the Sun controls temperature in the solar nebula

Temperature controls what materials will condense out of the solar nebula;

Too close to the sun it is too hot so nothing will condense-no planets will form inside the <i>rock-metal condensation line</i> "

Beyond the rock-metal line but inside the <i>frost line</i> only rock and metal will condense, gravitationally accreting into <i>planetisimals</i> , <i>protoplanets</i> and eventually into <i>terrestrial Planets</i>

Beyond the frost line, ices will form on rock-metal cores making the objects larger. Inside frost line, because of higher temperatures, gases are moving too fast for the smaller objects to gravitationally capture them

Beyond the frost line due to lower temperatures, the gases are moving more slowly and can be captured by the more massive ice-covered objects there allowing them to grow into the gas- giant <i>Jovian Planets</i>

The different temperatures at different distances from the Sun are the most important factor in determining what type of planet will form;
Small, rocky planets developed closer to the Sun where temperatures were higher
<i>Terrestrial</i> planets formed in essentially one-step-the accretion of rocks and metals
Large, gas-liquid planets developed farther from the sun where temperature were lower
<i>Jovian</i> planets formation had two additional steps-the accumulation first of ices then of gases

Not all materials become part of a planet or planetary-system;
Small rock-metal objects, closer to the sun, are called <i>asteroids</i>
Small rock-metal objects, farther from the sun, covered with ice are called <i>comets</i>
Both of these types of objects can collide with other object or be the source of objects that do that are called <i>meteoroids</i>

13.4 The Lecture Tutorial

The LT *The Formation of the Solar System* appears in Appendix 13.1. The current version is the result of several revisions based observations made during classroom use. One major change was to supply the graph in Figure 1 of the tutorial rather than having the students plot it themselves. This saved instructional time and just as many students (most of them) were correctly answering the second question in the tutorial and the first assessment question (both below) that temperatures in the solar nebula decrease with increasing distance from the Sun whether doing the plot themselves or just inspecting it.

13.5 Assessing the LT

The *Formation of the Solar System* LT was implemented and tested in the same fashion as the *Surface Conditions of Terrestrial Planets* LT in the previous chapter. The recommended methods for the use of an LT are discussed in detail in Chapter 5. An attempt to minimize instructor bias was again made by different instructors teaching different sections both by lecture and with the LT. The 7 assessment questions below were given as part of the *Solar System Survey* (Chapter 13) prior to and after instruction to compare the effectiveness of the solar system formation LT to that of lectures. The lecture given was similar the one transcribed above. As per recommended procedure (Prather and Brissenden, 2009, Prather et al., 2005) the sections doing the LT received only a brief introductory lecture, which basically consisted of the information in the introductory paragraph of the LT, see above, and a wrap –up afterward.

In Winter 2009 both sections that did the LT and those that received lectures on the topic were given formative assessment in a classroom-response/”clicker” format with the below assessment questions at the beginning of the next class period. Then in Fall 2009, the LT was tested as part of HPL-pedagogy in some sections against other sections that received lecture-only.

1. How did temperatures in the solar nebula (the material from which the planets formed) vary with distance from the Sun?
 - a. Temperatures got higher with increasing distance from the Sun.
 - b. Temperatures got lower with increasing distance from the Sun.
 - c. Temperatures remained about constant at all distances from the Sun.
 - d. [None of the above; temperatures varied in a random fashion]
2. The cores of the Jupiter-like planets are probably;
 - a. mostly solid and about the size of a Terrestrial planet.
 - b. mostly liquid and about the size of a Terrestrial planet core.
 - c. mostly gas and about the size of a Terrestrial planet.

- d. mostly ice and about the size of a Terrestrial planet core.
3. The determining factor in which kind of planet will form at a given location seems to be _____, which is controlled by _____.
- a. distance from the sun; temperature
 - b. temperature; distance from the sun
 - c. [distance from the sun only]
 - d. [temperature only]
4. Which is a correct list of the likely compositions of the different layers of a Jovian (Jupiter-like) planet going outward from the center?
- a. solid, liquid, gas
 - b. liquid, solid, gas
 - c. gas, liquid, solid
 - d. solid, gas, liquid
 - e. liquid, gas, solid
5. Which type of planet is more evolved (changed); which has gone through more steps in their formation?
- a. Terrestrial (Earth-like)
 - b. Jovian (Jupiter-like)
 - c. [Both types have gone through similar changes.]
 - d. [Neither type has gone through any changes since the initial step in their formation.]
6. Which is a correct list of the different types of planets that form in different regions of the solar system in an order going outward *from* the Sun?
- a. None, Terrestrial, Jovian
 - b. None, Jovian, Terrestrial
 - c. Terrestrial, None, Jovian
 - d. Jovian, Terrestrial, None

- e. [None of the above, different planet types can form in any region]
7. What do we now call the leftovers from the solar nebula after planetary formation, the material that did not become part of a planet?
- Asteroids
 - Comets
 - Meteoroids
 - [Any of the above]
 - [None of the above-the leftovers were blown away by the solar wind]

13.6 Results

Table 13.6.1 and Figures 13.3.1 & 13.6.2 show the results for the Winter 2009 semester (LT vs. lecture) and Table 13.6.2 and Figures 13.6.3 & 13.6.4 for the Fall 2009 semester (LT in HPL vs. lecture only).

	% Correct	% Correct	% Correct	Gain	Gain
Item #	Pretest N=100	Posttest (Lecture) N=46	Posttest Tutorial (N=38)	g-lec.	g-tut.
1	68	85	84	0.52	0.50
2	28	54	50	0.37	0.31
3	66	65	84	-0.02	0.54
4	44	72	63	0.50	0.34
5	17	46	45	0.35	0.33
6	44	63	79	0.34	0.62
7	44	57	74	0.22	0.53
Average	44.4	63.1	68.4	0.33	0.45
Standard Error	±7.0	±4.8	±6.1	±0.07	±0.05

Table 13.6.1 Pre and Post-test scores and normalized gains (Hake, 1998) for students receiving lectures and doing the LT *Formation of the Solar System* in Winter 2009. Standard errors in the average % score have a large overlap, while those of the average normalized gain just barely overlap.

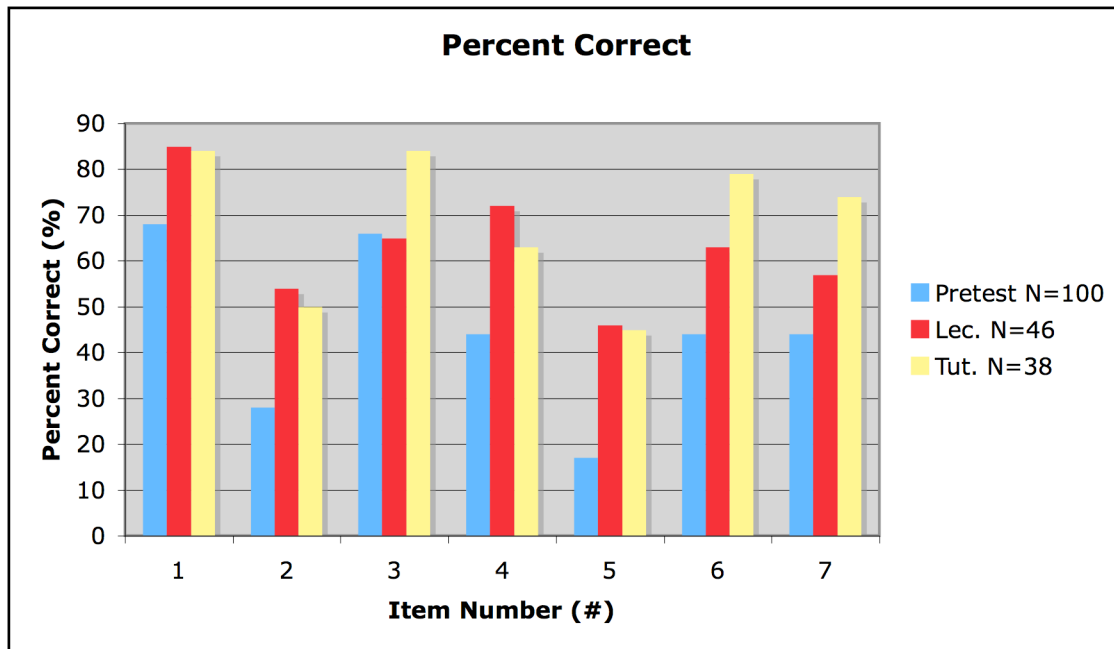


Figure 13.6.1 Percent of correct responses before (blue) and after instruction on assessment questions on solar system formation conditions in sections receiving lecture (red) and doing the LT (yellow) in Winter 2009.

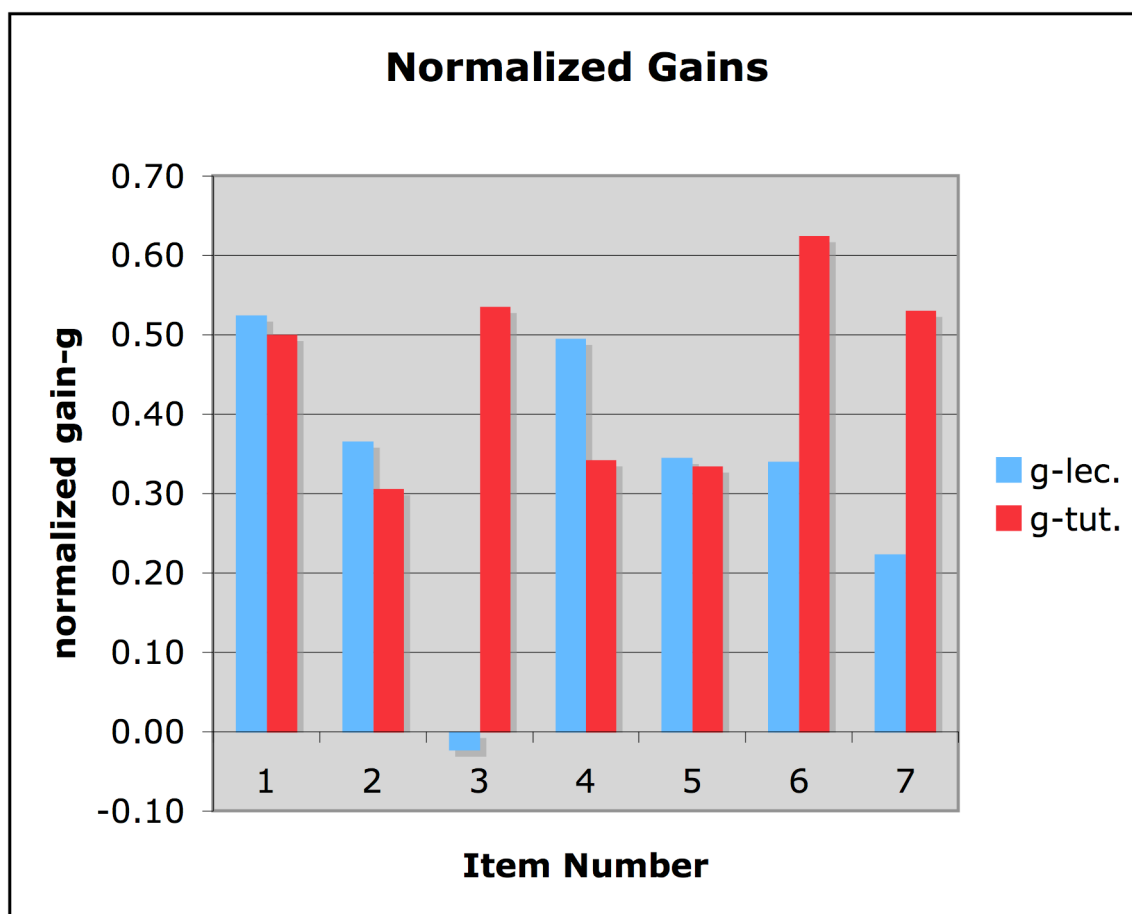


Figure 13.6.2 Normalized gains (Hake, 1998) on each item in the assessment of solar system formation in lecture (blue) and LT (red) sections during Winter 2009.

Despite the fact that the overlap of standard errors show these results not to be statistically significant, sections doing the LT had greater gains on nearly half the items and comparable gains on all other except one to the sections receiving lectures and a greater normalized gain without overlap in the standard error. Items 3 and 6 are about temperature, caused by distance from the Sun being the controlling factor whether planets will form and where each type of planet will form if they do. The much larger gains on these items by the tutorial group may have been due to the student attaining better understanding of solar system formation by being required to work through the process

steps than those were simply told about it (lectured to). Greater gains on item 7 about the types of solar system debris could have simply been due to the tutorial requiring students to think about what objects would be leftover in different regions of the solar system after planetary formation and write down their names rather than again, just being told that they were there.

As can be seen in Table 13.6.2 and Figs. 13.6.3 and 13.6.4 below, during the Fall 2009, when HPL-pedagogy was being compared to lecture only, HPL sections out-gained the lecture-only sections on all 7 items. The average gains and normalized gains by the HPL sections were greater, this time without any overlap in standard error, so the results are statistically significant.

Just as in the previous chapter, it is not surprising that the difference between the two in groups that the overall average gain and individual items was greater in the Fall 2009 when HPL-pedagogy was being compared to lecture-only than in Winter 2009 when the only LT was being testing. Again, the removal of formative assessment (Wilson & Sloane, 2000) in the “clicker” format (Duncan, 2007, Mazur, 2007) from the lecture sections is likely the main reason for the increased difference in gains between the groups in the two different parts of the study.

	% Correct	% Correct	% Correct	Gain	Gain
Item #	Pretest N=144	Posttest (Lecture- only) N=49	Posttest (HPL) N=72	g-lec.	g-HPL
1	69	80	83	0.35	0.47
2	36	31	67	-0.09	0.48
3	69	67	86	-0.07	0.55
4	31	55	67	0.35	0.52
5	15	12	64	-0.03	0.58
6	33	43	81	0.14	0.71
7	47	55	64	0.16	0.32
Average	42	49	73	0.12	0.52
Standard Error	±7.6	±8.6	±3.7	±0.07	±0.044

Table 13.6.2 Pre and Post-test scores and normalized gains (Hake, 1998) for students receiving lectures-only and doing the LT *Formation of the Solar System* as part of HPL-pedagogy in Fall 2009.

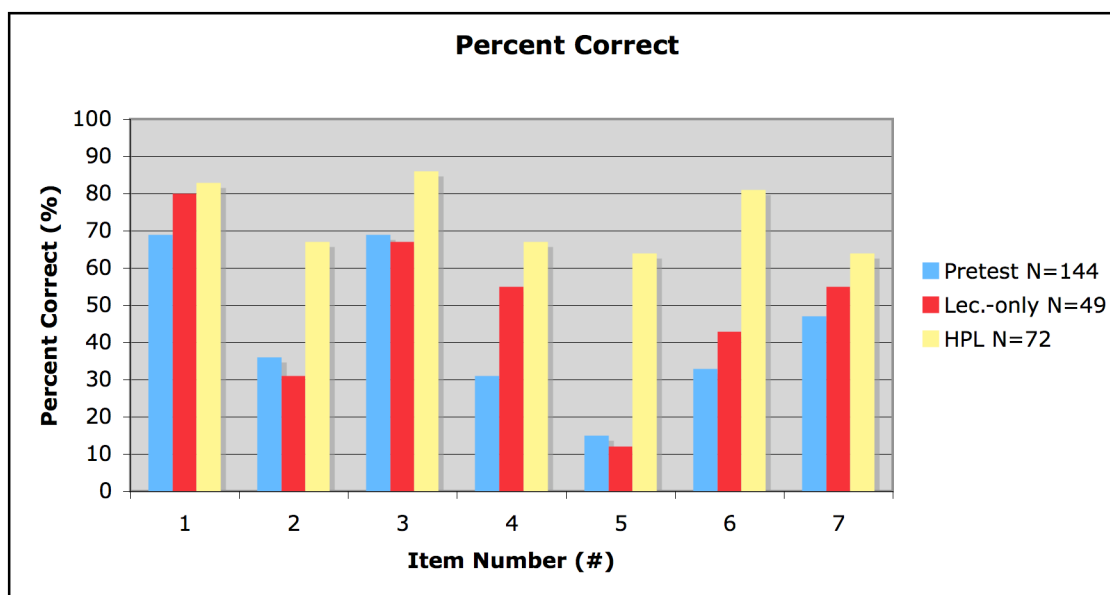


Figure 13.6.3 Percent of correct responses before (blue) and after instruction on assessment questions on solar system formation conditions in sections receiving lecture-only (red) and doing the LT as part of HPL-pedagogy (yellow) in Fall 2009.

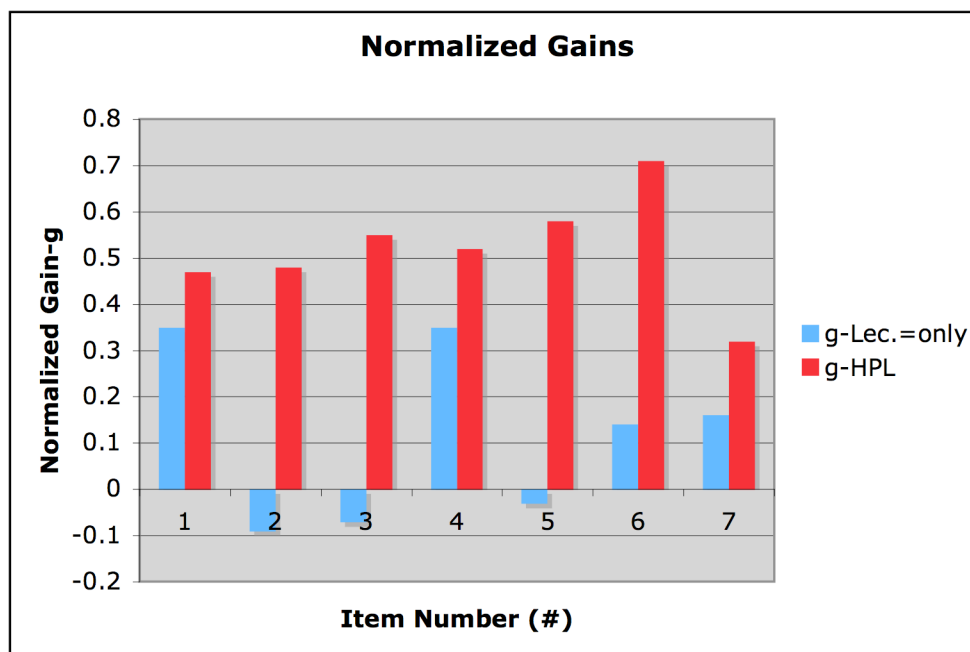


Figure 13.6.4-Normalized gains (Hake, 1998) on each item in the assessment of solar system formation in lecture-only (blue) and LT as part of HPL-pedagogy (red) sections during Fall 2009.

13.7 Another Trial

Similar to what was done in Chapter 6, another attempt was made to see if there was indeed any advantage to use the LT itself or if most of the advantage was due to the use of clickers in HPL pedagogy. During the Fall 2010 semester no sections received formative assessments in a classroom response format. Two sections each taught by a different instructor received lectures on solar system formation while three sections, all taught by a third instructor, did the most recent version of the tutorial. With the hope of minimizing instructor bias and the Hawthorne effect (Hake, 1998, from Slavin, 1992), none of the sections involved were taught by the author. Also, as in Chapter 6, at the suggestion of the instructors involved, based largely on previous student feedback, the assessment questions used were modified to read as follows;

1. How did temperatures in the solar nebula (the material from which the planets formed) vary with distance from the sun?
 - a. Temperatures got higher with increasing distance from the sun.
 - b. Temperatures got lower with increasing distance from the sun.
 - c. Temperatures remained about constant at all distances from the sun.
 - d. Temperatures varied in a random fashion.
2. The cores of the Jupiter-like planets are probably;
 - a. mostly solid and about the size of a Terrestrial planet.
 - b. mostly liquid and about the size of a Terrestrial planet core.
 - c. mostly gas and about the size of a Terrestrial planet.
 - d. mostly ice and about the size of a Terrestrial planet core.
3. The main factor(s) in determining which type of planet will form at a given location seems to be
 - a. distance from the Sun.
 - b. temperature.
 - c. temperature, which is caused by distance from the Sun.
 - d. neither distance from the Sun or temperature matter.
4. Which is a correct list of the likely compositions of the different layers of a Jupiter-like (Jovian) planet going outward from the center?
 - a. solid, liquid, gas
 - b. liquid, solid, gas
 - c. gas, liquid, solid
 - d. solid, gas, liquid
 - e. liquid, gas, solid

5. Which type of planet is more evolved (which type has gone through more steps in their formation)?
- Earth-like (terrestrial)
 - Jupiter-like (Jovian)
 - Both types have gone through similar steps in their formation.
 - Neither type has gone through any changes (evolved) much at all since the initial step in their formation.
6. Which is NOT true about the solar nebula?
- Too close to the Sun (inside the rock-metal line) no materials could condense out of the solar nebula.
 - Rocks and metals only condense in between the rock –metal line and the frost line.
 - Ices could only condense out of the solar nebula at farther distances from Sun (beyond the frost line).
 - Gases were slower moving and therefore more likely to be gravitationally captured by planets in parts of the solar nebula farther from the Sun.

Results are shown in Table 13.7. 1.

	% Correct	% Correct	% Correct	Gain	Gain
Item	Pretest N=116	Lec. N=36	Tut. N=65	g-lec.	g-tut.
1	69.8	77.8	89.2	0.26	0.64
2	25.0	38.9	55.4	0.19	0.41
3	45.7	58.3	53.8	0.23	0.15
4	43.1	66.7	70.8	0.41	0.49
5	12.9	19.4	80.0	0.07	0.77
6	24.1	30.6	30.8	0.08	0.09
Average	36.8	48.6	63.3	0.21	0.42
Standard Error	±8.3	±9.2	±8.6	±0.05	±0.11

Table 13.7.1 Pre and Post-test scores and normalized gains (Hake, 1998) for students receiving lectures and doing the LT *Formation of the Solar System* in Fall 2010. There is slight overlap in the standard error of the average % scores, but not in that of the average normalized gain.

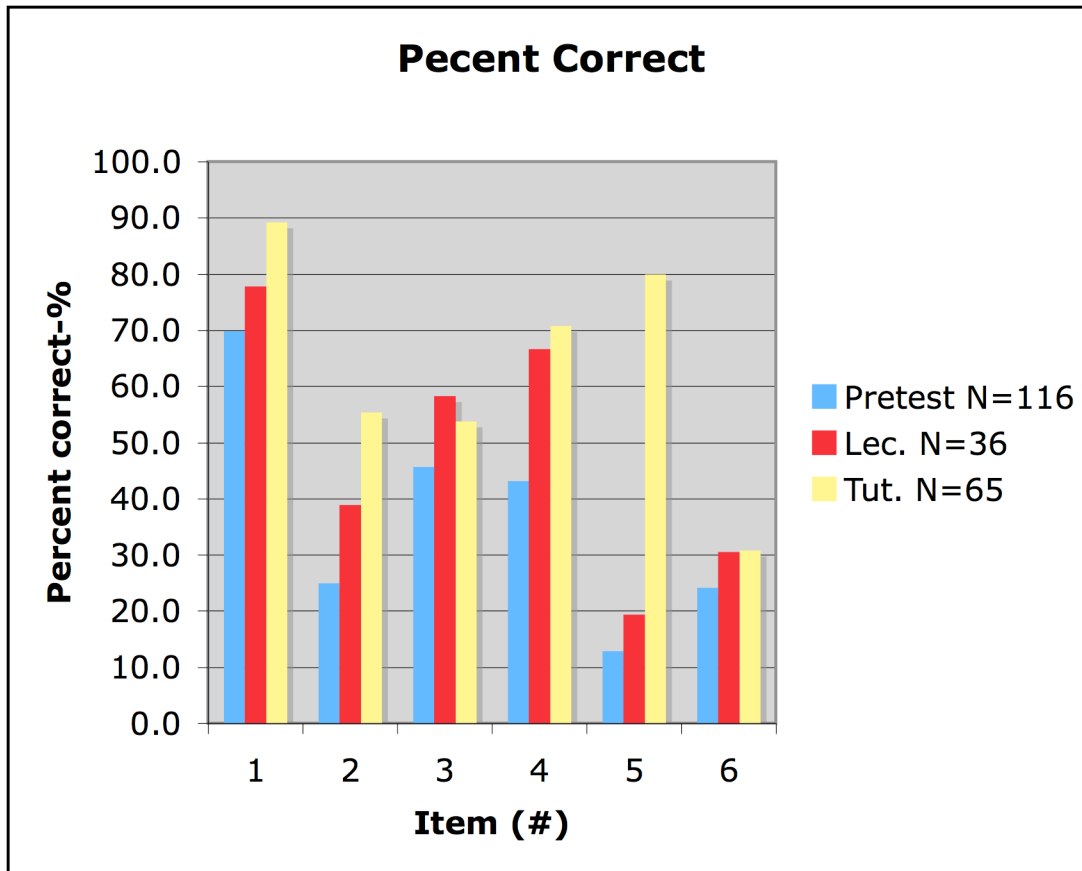


Figure 13.7.1 Percent of correct responses before (blue) and after instruction on assessment questions on solar system formation conditions in sections receiving lecture (red) and doing the LT (yellow) in Fall 2010. The tutorial group out gained the lecture group on three items with gains appearing comparable on the other three.

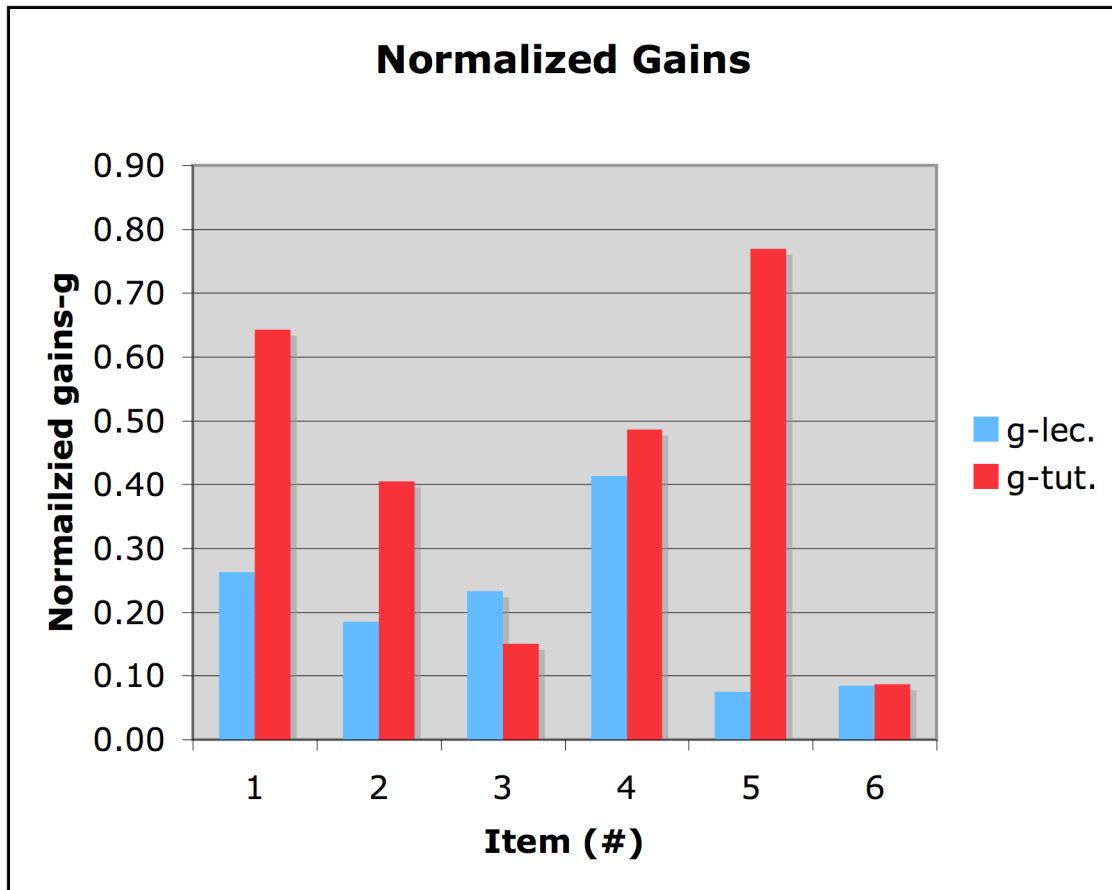


Figure 13.7.2 Normalized gains (Hake, 1998) on each item in the assessment of solar system formation in lecture (blue) and LT (red) sections in Fall 2010.

Chapter 14

The Solar System Survey

14.1 Introduction

The *Solar System Survey* referred to in previous chapters is an instrument developed specifically to assess the effectiveness of the activities and tutorials described in Chapters 8-12. It was used to specifically compare the activities to lectures on the same topics during the Winter 2009 semester and the activities when used as part of HPL pedagogy to instruction by lecture-only during the Fall 2009 semester. The survey is *not* meant to be a general concept inventory on solar system topics such as the *Solar System Concept Inventory*, SSCI (CAE- CATS projects, <http://astronomy101.jpl.nasa.gov/cats/projects/>) that is under development or the SPCI (Bailey, 2008) used in the pilot research project described in Chapter 7.

14.2 Development (Fall 2008)

The survey was developed largely in the Fall 2008, the semester prior to those in which it was used. At the beginning of the class period after students had either done early versions of the activities or received lectures on the same topics, they were given a formative assessment consisting of completion questions. They were permitted to discuss the questions in groups, but all students were asked to write out and submit their own answers.

For example, below are the questions assigned after coverage of planetary types, either by the *Comparative Planetology Activity* described in Chapter 9 or a lecture on the topic.

1-Name two types of planets found in our solar system.

Terrestrial, Jovian

2-List the planets that are members of each group.

Mercury, Venus, Earth, Mars;
Jupiter, Saturn, Uranus, Neptune

3- List three of the properties that define each group of planets.

Size, Mass, Density, Distance from the Sun, Number of Moons (among others)

4-What *one* word could be used to describe how the properties of the planets in one group compare to the properties of the planets in the other group?

Opposite

5-Which planet does not fit into either group? Why does it not fit in?

Pluto, it does not fit the properties of either category

The students' written answers were examined and the multiple choice questions were formulated based on both the correct and incorrect responses. For example, "lower density" was a recurring incorrect response to listing properties of terrestrial planets in question 2 above as was "higher density" when listing Jovian planet properties. So, in question 2 of the multiple-choice *Solar System Survey* shown below, "higher density" was used as correct response as the one property in a list that was *not* characteristic of terrestrial planets.

This could have been due to a lack of student understanding of density or it could have been simply due to not reading the question well enough or not thinking about it. All the other properties of terrestrial planets, size, mass, distance from the Sun, etc. are *less* than those of Jovian planets, so if proper thought is not given to the question, density could be “lumped-in” with the other properties as also “less” and therefore “lower”.

Other common mistake in the above completion questions were incomplete lists of each planetary group and Pluto being listed as a member of one of the groups. This is the reason for including questions 1 and 3 in the *Solar System Survey* shown below about the members of each group and Pluto appearing as a distracter (an incorrect response) in each. This was also because less than about 60 % of respondents to the fifth completion question above retained correctly identified Pluto as the planet that did not fit into either major category. Although quantifying results to the completion questions was more difficult, when compared to one another, there did not seem to be a large difference in responses between the group doing the activities or those hearing lectures only.

Questions 1-5 of the *Solar System Survey*, shown below, pertaining to planetary types were developed from the above five completion questions with the purpose of comparing the *Comparative Planetology Activity* (Chapter 9) to lectures on this topic.

The completion questions used to develop questions 6-12 (below) of the *Solar System Survey* pertaining to solar system formation used to compare the Lecture Tutorial, *Formation of the Solar System* to lectures (Chapter 12) were;

1-How do temperatures in the solar nebula vary with distance from the Sun?

Temperature decrease with increasing distance from the Sun

2-List in order what types of planets form at different distances from the Sun.

None, Terrestrial, Jovian

3-What is the most important factor in determining what type of planet will form, what controls this factor?

Temperature, distance from the Sun

4-Describe the internal structure, the composition of the layers, of a Jovian planet from the inside out.

Solid, liquid, gas

5-Which type of planet is most evolved, has gone through the most changes?

Jovian

6-What do we call object that did not become part of a planet?

Asteroids, Comets, Meteoroids

Most respondents answered the first question, that temperatures decreased with distance from the sun, correctly. A common mistake in the second question, on listing the regions of planetary formation was to respond, Terrestrial, Jovian, none, rather than, none, Terrestrial, Jovian. This could have been due to confusion that the question was about identifying that Pluto, beyond the Jovian planets, is not a planet. To eliminate the possibility of this confusion, Terrestrial, Jovian, none, was *not* included as a distracter in question 11 of the *Solar System Survey*. It was also common in the third question to see the responses listed; *distance, temperature*, instead of the reverse. This could have been

just an error in how they were listed but it could also have been evidence of not understanding the correct cause and effect relationship. Terrestrials were often listed as more evolved for the fifth question. Anecdotally, instructors had overheard students say that “evolution happened on Earth.” The list for the last question was often incomplete.

Questions 13-22 (below) of the *Solar System Survey* that were used to compare the Lecture Tutorial, *Surface Conditions of Terrestrial Planets* to lectures (Chapter 11) were developed with the following completion questions about the topic.

1-What processes are involved in the shaping of Terrestrial planet surfaces?

Cratering, Erosion, Tectonics & Volcanism

2-What factor(s) has (have) most effects on the development of a Terrestrial planet’s atmosphere?

*Surface Temperature (caused by distance from the Sun)
Mass (size)*

3-What factor controls the amount of geological activity on a Terrestrial planet?

Size (mass)

4-Which processes will likely have the most affect on a small Terrestrial planet?

Cratering

Most respondents were able to list all four processes for the first question. Many listed size and not temperature for the second question. Perhaps this is because the size (and mass) of planet determines whether or not the planet will initially have an atmosphere and how thick it will be. Size and temperature were also often both listed for the third question. This could have been due to confusion between surface and internal temperatures. Most responses to the fourth question were correct.

The final three questions (23-25) of the Solar System Survey were developed based on commonly known misconceptions about comets discussed in Chapter 10. All 25 questions of the *Solar System Survey*, used in the studies described in Chapters 9-12 can be found in Appendix 14.1.

14.3 Validation (Fall 2008)

The first version of The *Solar System Survey* was given as a posttest several weeks after the end of solar system coverage during the Fall 2008 semester to several sections of the same group of students who's formative assessments were used to created the distracters for the multiple-choice questions. At the same time, several other sections from this group were given the same completion question from the earlier formative assessment as a posttest. The percentages of students responding to each choice on each multiple-choice question were compared to the responses of the students on the completion posttest. The majority of the results were similar. Since this was the case, those were considered satisfactory questions with satisfactory distracters. In the cases where the results from the two groups were not as similar, the wording of the question and the distracters were examined in more detail and in a number of cases amended, or in a few changed completely.

14.4 Results (Winter 2009)

The *Solar System Survey* was administered as a pretest prior to any solar system coverage and as a posttest approximately a week after the exam on solar system topics during the Winter and Fall 2009 semesters. Gains on individual questions on specific topics were discussed throughout chapters 9-12. Results for the entire survey are reported here.

Table 14.3.1 shows the pretest results and posttest results and normalized gains (Hake 1998) for the lecture and tutorial sections during the Winter 2009 semester. Figures 14.3.1 and 14.3.2 are plots of these results. Inspection of Table 14.3.1 shows that on the survey as a whole, students in the tutorial sections average score was higher by more than

the standard error than those in lecture sections, but there was some overlap. Their normalized gain was also higher without any overlap in the standard errors.

Figure 14.3.3 is a plot of the number of students scoring 0-25 on the pretest and the posttests lecture and tutorials sections during the Winter 2009 semester.

As previously discussed in Chapters 9-12 about the individual activities, during the Winter 2009 semester, the survey scores of sections that did the activities and tutorials were compared to those that received lectures on the same subjects *with the purpose of testing the effectiveness of the activities*, so *both* groups were given the survey questions as formative assessments in a classroom response/"clicker" format.

	% Correct	% Correct	% Correct	Gain	Gain
Item#	Pretest N=100	Posttest (lecture) N=46	Posttest (tutorial) N=38	g-lec.	g-tut.
1	48	78	84	0.58	0.70
2	19	57	53	0.46	0.42
3	49	85	89	0.70	0.79
4	43	85	84	0.73	0.72
5	40	63	61	0.38	0.34
6	68	85	84	0.52	0.51
7	28	54	50	0.37	0.31
8	66	65	84	-0.02	0.54
9	44	72	63	0.50	0.34
10	17	46	45	0.35	0.33
11	44	63	79	0.34	0.62
12	44	57	74	0.22	0.53
13	66	76	84	0.30	0.54
14	12	43	42	0.36	0.34
15	24	26	29	0.03	0.07
16	20	57	58	0.46	0.47
17	14	33	37	0.22	0.27
18	33	41	53	0.12	0.29
19	16	24	29	0.09	0.15
20	28	28	42	0.00	0.20
21	61	57	74	-0.11	0.33
22	24	28	42	0.06	0.24
23	14	48	55	0.39	0.48
24	35	46	63	0.16	0.43
25	35	63	58	0.43	0.35
Average	35.7	55.2	60.6	0.31	0.41
Standard Error	±3.5	±3.8	±3.7	±0.045	±0.036

Table 14.3.1 Student percentages scores on each item of the pretest and posttest in lecture and tutorial sections and normalized gain for the Winter 2009 *Solar System Survey*.

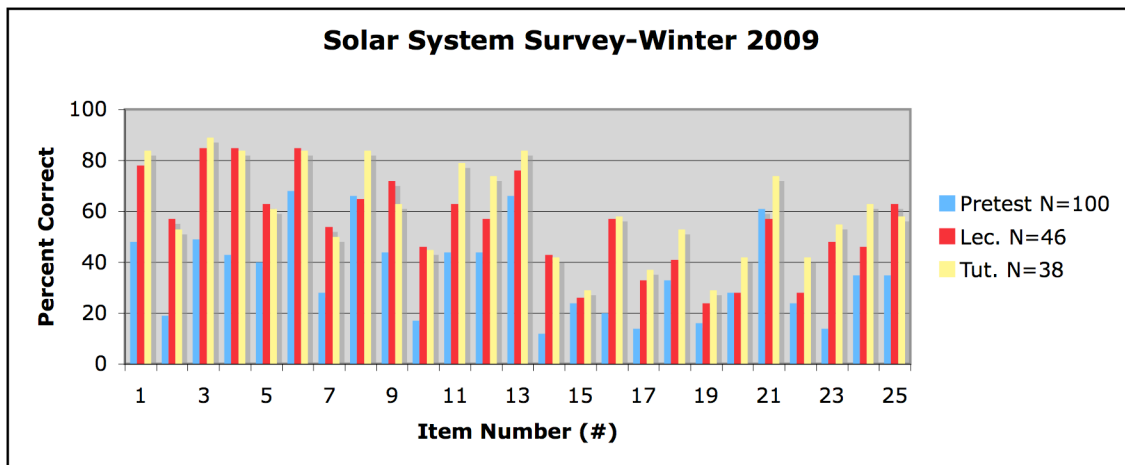


Figure 14.3.1 Plot of student percentages scores on each item of the pretest (blue) and posttest in lecture (red) and tutorial (yellow) sections for the Winter 2009 *Solar System Survey*.

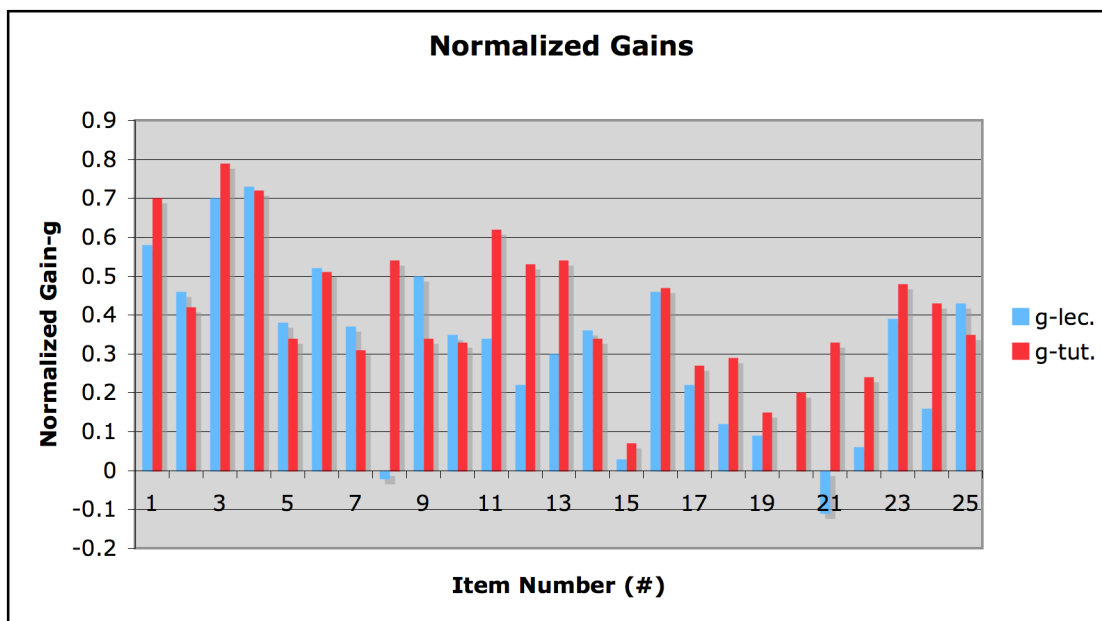


Figure 14.3.2 Normalized gain for each item in the lecture (blue) and tutorial (red) sections for the Winter 2009 *Solar System Survey*.

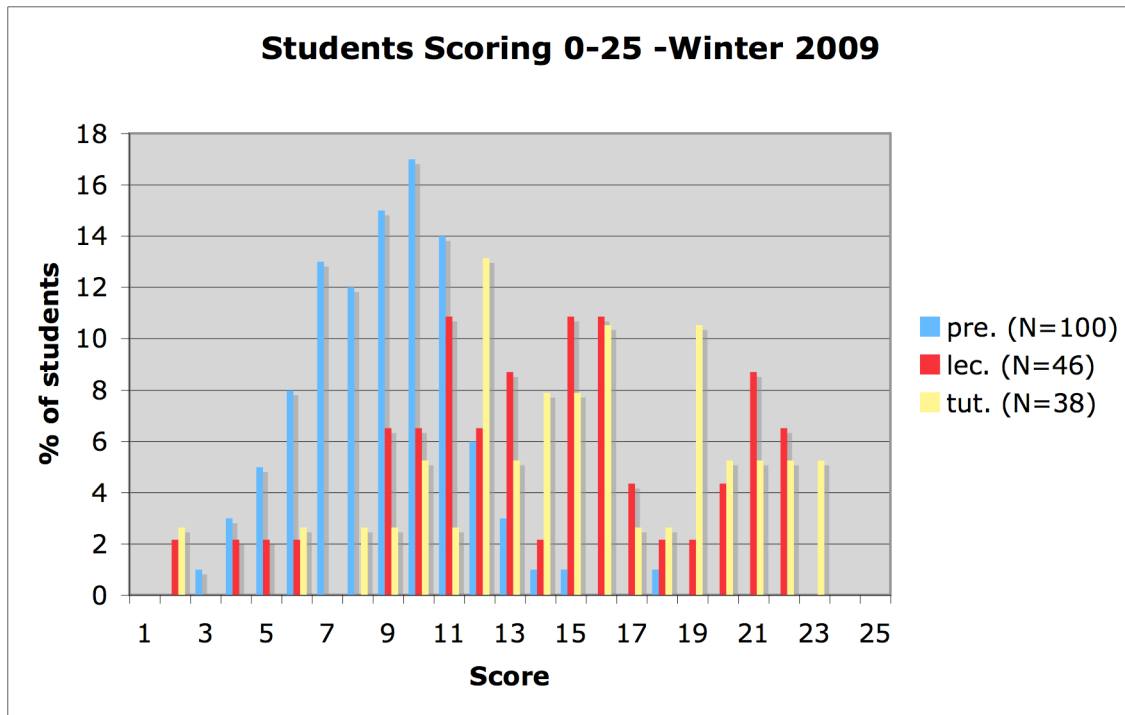


Figure 14.3.3 Percentage of students scoring 0-25 on the pretest (blue) and posttest in lecture (red) and tutorial (yellow) sections for the Winter 2009 *Solar System Survey*.

14.5 Results (Fall 2009)

Table 14.4.1 shows the pretest results and posttest results and normalized gains (Hake 1998) for the lecture and tutorial sections during the Fall 2009 semester. Figures 14.4.1 and 14.4.2 are plots of these results. On the survey as a whole, students in the HPL sections out gain students in the lecture-only sections on both the average scores and normalized gains without overlaps in standard error.

Figure 14.4.3 is a plot of the number of students scoring 0-25 on the pretest and the posttests lecture and tutorials sections during the Fall 2009 semester.

	% Correct	% Correct	% Correct	Gain	Gain
Item #	Pretest N=144	Posttest (Lec-only) N=49	Posttest (HPL) N=72	g-lec. only	g-HPL
1	51	80	78	0.59	0.55
2	21	53	56	0.41	0.44
3	44	78	85	0.60	0.73
4	28	67	76	0.54	0.67
5	30	45	61	0.21	0.45
6	69	80	83	0.35	0.47
7	36	31	67	-0.09	0.48
8	69	67	86	-0.07	0.55
9	31	55	67	0.35	0.52
10	15	12	64	-0.03	0.58
11	33	43	81	0.14	0.71
12	47	55	64	0.16	0.32
13	65	69	92	0.14	0.76
14	8	20	44	0.14	0.40
15	30	22	42	-0.11	0.17
16	17	41	78	0.28	0.73
17	15	29	38	0.16	0.26
18	28	27	65	-0.03	0.51
19	17	8	25	-0.11	0.09
20	28	20	39	-0.10	0.15
21	53	71	82	0.39	0.62
22	21	22	36	0.02	0.19
23	11	53	63	0.47	0.58
24	23	51	78	0.36	0.71
25	33	41	51	0.11	0.27
Average	33	46	64	0.19	0.48
Standard Error	±3.5	±4.4	±3.7	±0.046	±0.04

Table 14.4.1 Student percentages scores on each item of the pretest and posttest in lecture-only and HPL-tutorial sections and normalized gain for the Fall 2009 *Solar System Survey*. Note that this time there is no overlap in standard errors of the % scores and normalized gains.

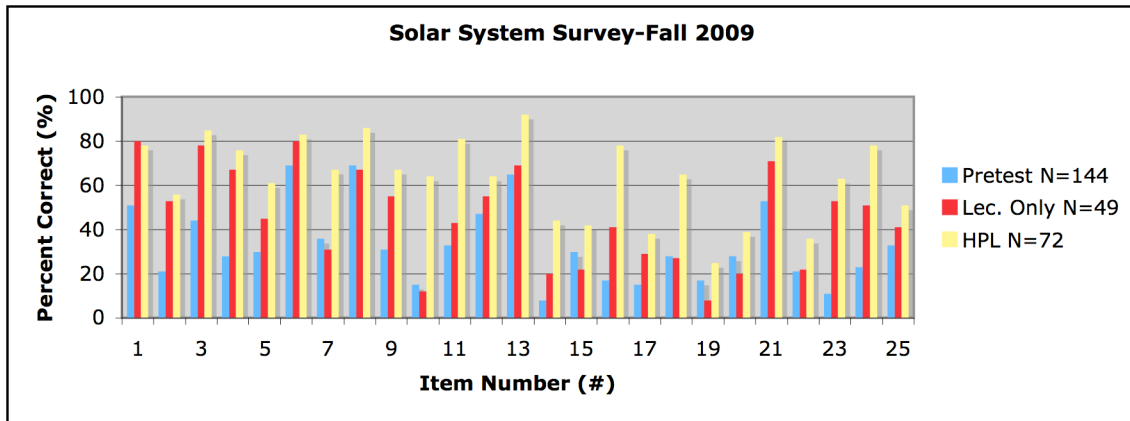


Figure 14.4.1 Plot of student percentages scores on each item of the pretest (blue) and posttest in lecture-only (red) and HPL-tutorial (yellow) sections for the Fall 2009 *Solar System Survey*.

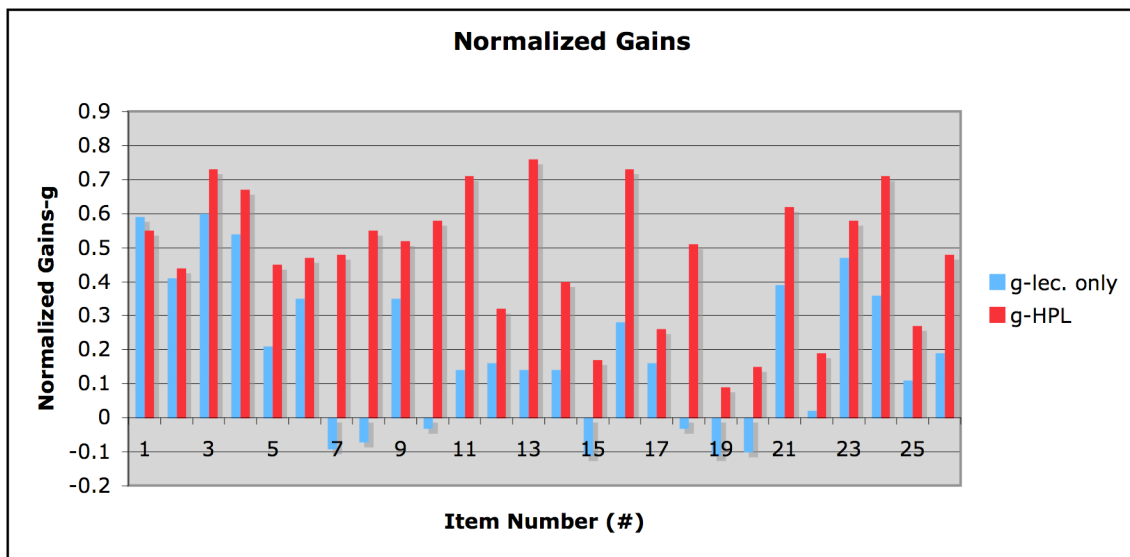


Figure 14.4.2 Normalized gain for each item in the lecture-only (blue) and HPL-tutorial sections (red) for the Fall 2009 *Solar System Survey*.

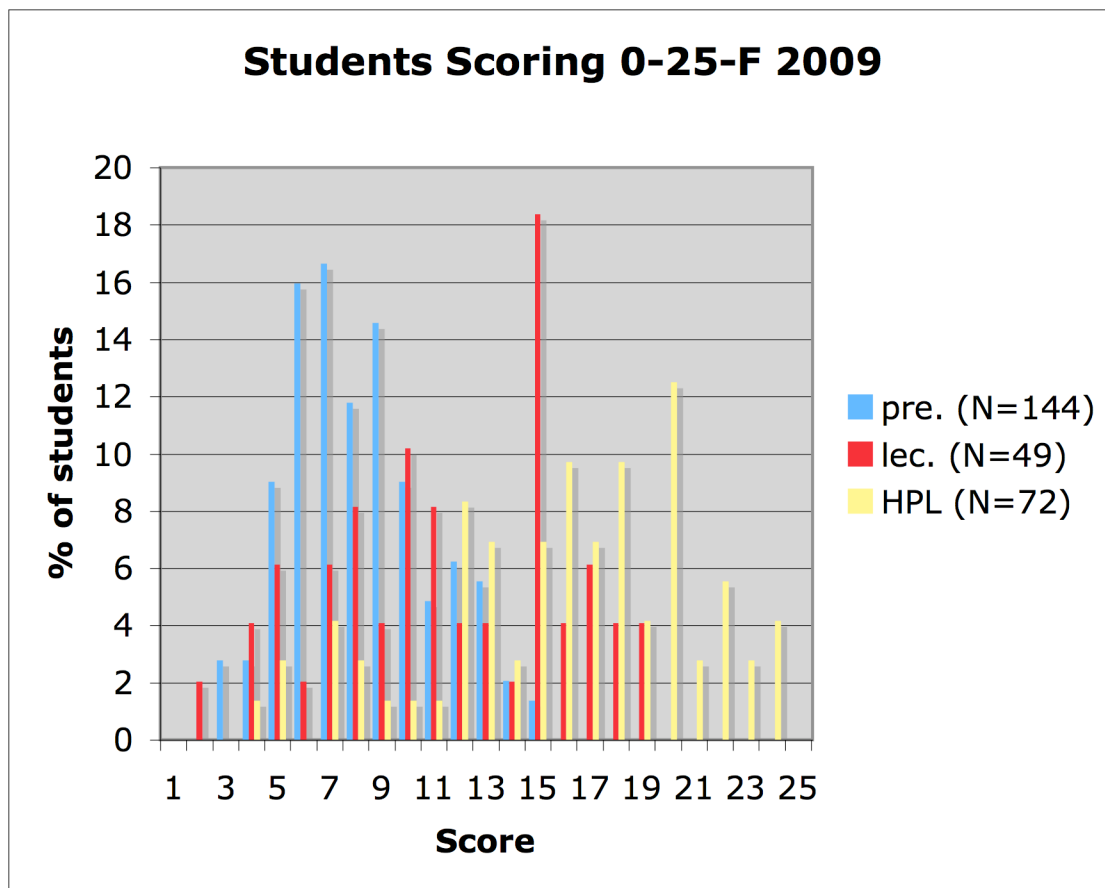


Figure 14.4.3 Percentage of students scoring 0-25 on the pretest (blue) and posttest in lecture-only (red) and HPL-tutorial (yellow) sections for the Fall 2009 *Solar System Survey*.

Recall that during the Fall 2009 semester, survey scores of sections that were taught with HPL-pedagogy were compared to those that received lectures-only on the same subjects. This means that the sections that did the activities and tutorials *were* given the survey questions as formative assessments in a classroom response/"clicker" format as part of the HPL-pedagogy, while the lecture-only sections were *not*. So, again, as discussed in the chapters about the individual activities that the items were used to assess, it is not surprising that differences in gains between groups increased from Winter 2009 to Fall 2009, the gains of the lecture-only sections being less in Fall 2009 than the lecture sections that still received formative assessments in Winter 2009.

14.6 Conclusion

The results of the *Solar System Survey* as a whole showed statistically significant greater gains by the students doing the tutorials than those receiving lectures (Winter 2009) and an increased difference between groups being taught with HPL-pedagogy and those being taught by lecture-only (Fall 2009). This and the results of comparisons with the individual activities and tutorials (Chapters 8-13) does suggest that students will indeed experience greater educational gains when actively engaged and/or in group discussions through the use of learned-centered activities such as tutorials and classroom response systems, the latter especially when used in formative assessment.

The *Solar System Survey* was no longer given in its entirety after Fall 2009. Further assessments during Fall and Winter 2010 and 2011 and Fall 2011 were done for individual activities with the subject appropriate questions from the survey. As indicated in the chapters on the individual activities many of the questions had by this time been revised. Revisions were based on suggestions from instructors teaching the sections involved in the study, largely due to feedback from students on which questions or parts of questions may have been confusing or unclear.

Chapter 15

Affective Data

15.1 Introduction

Student opinions were surveyed both at the beginnings and ends of the semesters. At the beginning of the term they were asked questions about themselves and why they were taking astronomy and what they thought it was. At the end of the term they were asked what they thought of the different teaching methods used and how they learned from them.

15.2 A “*Student Survey*”

On the first day of class students were instructed to download the syllabus from the class website and complete the following *Student Survey* that was to be turned in on the second day of class along with their signature on a statement that says that they read the syllabus and agreed to abide by its contents.

Although some of the highlights were covered, class time was not spent going over the syllabus in its entirety. Doing that is the best way to guarantee that students *will not* read it. In learner-centered teaching, where the responsibility for learning is placed with the student, being aware of class policies and procedures should be part of that responsibility. Later in the course, when questions pertaining to these issues are asked, the answer should be a polite, “please read the syllabus.” (Weimer, 2002)

Student Survey

What do you hope to achieve by (or why are you) attending Henry Ford Community College?

What do you hope to do after attending HFCC?

What is (are) your major and/or interests?

Why are you taking Astronomy at HFCC?

What do you think Astronomy is?

What do you want/hope to learn in Astronomy?

As would be expected in a general-education course, a wide variety of major were represented. About 20% of students were majoring in Criminal Justice, most hoping to become police officers. 13% each aspired to be teachers or to enter a medical field, nursing, physical therapy or respiratory therapy chief among them. Another 13% were studying one of the arts; visual arts, music or theater. About 10% were interested in business. Note that these areas all represent well-established programs at HFCC. Of the rest, 16% were interested in a combination of social sciences (particularly psychology), humanities and the media. 12% were undecided. Only 3% were planning to major in science or mathematics. All the science students were interested in life science, none indicated career interest in the physical sciences. This small percentage of science students is not surprising since the introductory astronomy course is a general education and not a major's science course.

Again, the above demographics are not surprising. Nor is it surprising that 23% of students responded that they were taking astronomy because it was required or they needed a science credit. It was refreshing that over a third, 35% indicated that they took the course out of interest and that 42%, although indicating that needing science credit was a factor, indicated that the subject was also of interest to them. It was often stated that among the choices of courses for general education science credit, astronomy sounded the most interesting

What was perhaps most encouraging was that when asked what they thought astronomy was or what they hoped to learn, 93% of students seemed to have realistic expectations from the course. Most mentioned one or more of the following terms; science, theories, the universe and its origins, space, the sky, stars, constellations, galaxies, the Milky Way, the solar system, planets, Earth, the moon, comets and asteroids.

Of the minority with unrealistic expectation responses included, the workings of the Earth or the world, weather and aliens. Interestingly, the only mention of astrology was one student who actually stated that he expected “*not* to learn how to cast horoscopes.”

These results are mostly consistent with research conducted on student expectations of what will be covered in introductory astronomy. (Slater and Adams, 2003, adapted from Lacy and Slater, 1999)

15.3 An “*Attitude Survey*”

At the end of the semester, students were given the following *Student Attitude Survey*.

Student Attitude Survey

For Questions 1-6 A=Strongly Agree
 B=Agree
 C=Neutral
 D=Disagree
 E=Strongly Disagree

- | | | | | | | |
|----|---|---|---|---|---|---|
| 1. | I like doing Tutorials (Activities). | A | B | C | D | E |
| 2. | I like hearing lectures. | A | B | C | D | E |
| 3. | I learn from doing Tutorials. | A | B | C | D | E |
| 4. | I learn from hearing Lectures. | A | B | C | D | E |
| 5. | I like using classroom responders | A | B | C | D | E |
| 6. | I learn from using classroom responders | | | | | |
| | | A | B | C | D | E |

7. I like _____ better.

A=Tutorials
 B=Lectures
 C=Both
 D=Neither
 E=Not Sure

IN THE SPACE BELOW-WRITE ANY COMMENTS YOU MAY HAVE ABOUT TUTORIALS OR CLASSROOM RESPONDERS

Table 15.3.1 shows the percent of N=264 students responding A-E to items 1-4 at the end the Winter 2008 and Winter and Fall 2009 semesters. Items 5 and 6 on classroom responders were only added for the end of the Fall 2009 semester, N=76 students. Figure 15.3.1 is a plot of this data.

	A	B	C	D	E
	S. Agree	Agree	Neutral	Disagree	S. Disagree
I like tutorials	46	33	15	3.4	3.0
I like lectures	45	28	19	3.0	4.9
I learn from tutorials	55	27	11	2.3	4.9
I learn from lectures	59	27	11	1.2	2.3
I like responders	50	35	12	1.4	1.4
I learn from responders	47	37	12	2.6	1.3

Table 15.3.1 Percentage of students responding to A-E on each item of the *Student Attitude Survey*.

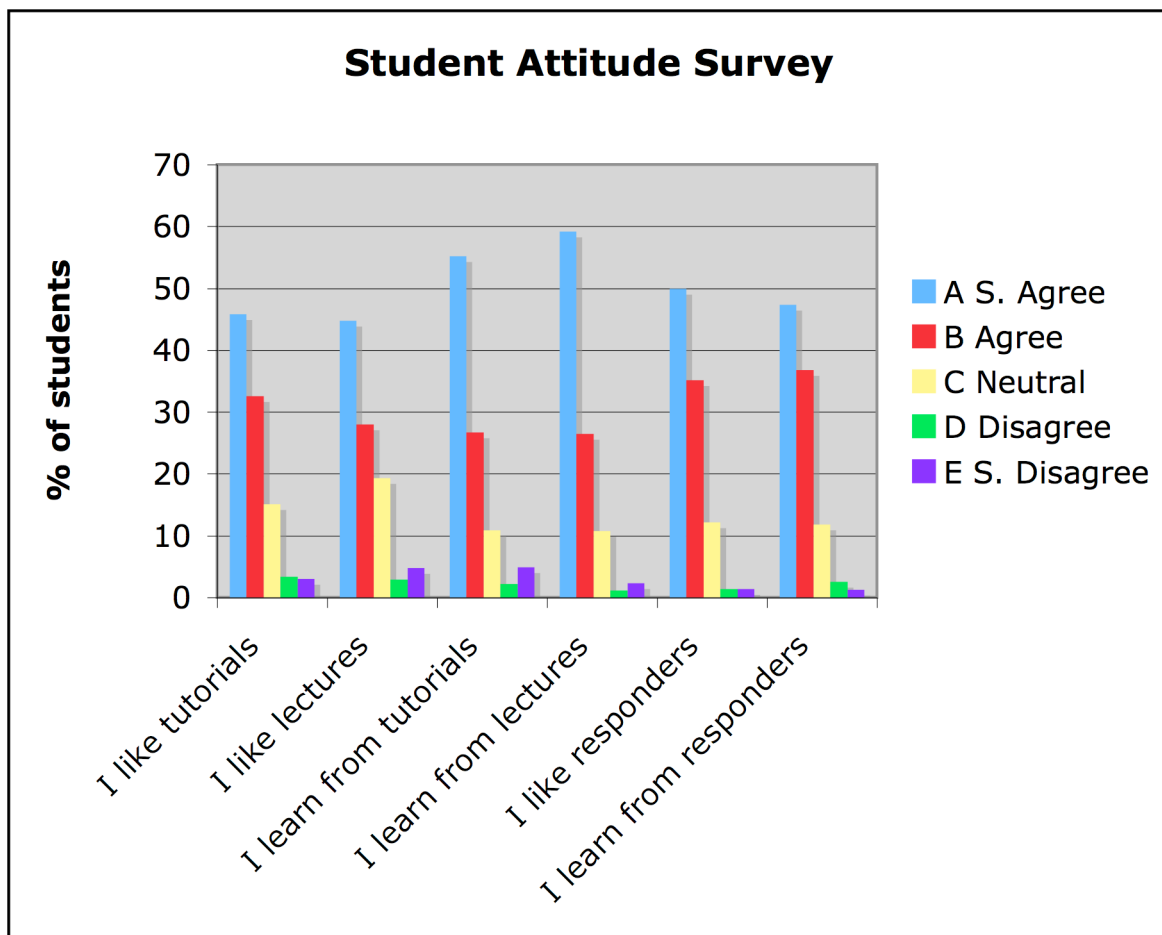


Figure 15.3.1 Plot of the results of the *Student Attitude Survey*.

For item 7 on whether they liked lectures or tutorials better, about 30% of the N=264 students chose tutorials, while 26% chose lectures. 38% chose that they liked them both. Almost 4% said they liked neither. About 2% were unsure.

Positive comment about tutorials were that they were “hands on”, forced you to “participate” and lead to “good discussions.” Also that they “required thought,” and made you “think for yourself,” allowed you learn “step by step” and that they make you check answers “as you go.” Although considered by some, “challenging” and “confusing,” they “help you remember, “gave understanding” and were “satisfying” when completed.

There were many fewer negative comments, but the most common was that tutorials should be graded or that an answer-key should be given. The originators of this pedagogy recommend that neither of these be done . The reasoning is that once the answers are circulated many students will just “find” and try to memorize answers and no longer work the tutorials. This will cause the tutorials to lose their effectiveness as teaching tools. (Brogt, 2007, Prather 2008) That they should be given as homework or given more class-time because people work at different paces was mentioned as was that more background on a topic should “given” before tutorials were assigned and that were “hard to learn from.”

Positive comments about classroom responders were that, like tutorials, they lead to “good discussions,” that they forced you to “get involved” which helped you “learn better,” and that they were good for review. There were comments that students liked them being used diagnostically, while others said they did not like them being used in that fashion. Some even said they were “fun” and “game-like.”

One student said that they thought that classroom responders were going to be “crap,” but was surprised how good the discussions that resulted from them were. Another described them as “annoying, but helpful.” One wished that the questions would be the ones that would be on the tests. The few negative comments included one student that simply did not like them and another that “could do without “ them.

More general comments about both pedagogies were that they were “both good methods,” “fun, new ways to learn,” encouraged “hands-on” work and “working together.” Also that they were useful for “different learning styles” and were good because they helped students see the various topics in more than one way and “solidified” the information. One particularly insightful student’s comment was that the combination of lectures, tutorials and classroom responders were a “good-mix” of “great methods” to “help us learn.”

A few students mentioned that although they could learn from lectures, seeing the material in different ways helped and they appreciated that others might have different learning styles than they did. One student commented that although they liked lectures the best, they were hard to focus on and it was good that other teaching methods were included in the course. Only a few students made a point of commenting specifically that they preferred lectures.

The data gathered here seems to be in line with other research done on student attitudes about the use of both Lecture Tutorials (Prather et al. 2005) and classroom response systems/“clickers.” (Duncan, 2007, Prather & Brissenden, 2009)

The data in Table 15.3.1 and Figure 15.3.1 does not show that students have a strong preference for either lectures or active-learning, nor that they perceive themselves as learning much better from one or the other. Their comments, however, may offer some insight as to why in the assessments of the activities in the this study, active and collaborative learning repeatedly showed higher gains than lectures. As can be seen in the above summary of comments, students referred to being challenged, thinking for themselves, getting involved and group discussions as helping them learn. These comments reflect that what students *think* is helping them learn is doing things for themselves rather than be told about them, and working with others instead of alone. This is very essence of active and collaborative learning and is also what the data taken in the work has shown *does* indeed help students learn.

Chapter 16

Conclusions

16.1 Student Attitudes

When asked if they liked and if they learned from the pedagogies used for instruction, a majority of the introductory astronomy students surveyed responded positively to lectures, tutorials and classroom responders/"clickers." There were many more positive comments about active pedagogies, tutorials and classroom response, than negative ones. When asked whether they liked tutorials or lectures better, there was not a strong consensus, but as seen in Chapter 15, more replied that they liked them both than one or the other. As discussed at the end of Chapter 15, specific student comments about thinking for themselves and working with others helping them learn correlated directly with data presented in Chapters 7-13 of this work and other previous studies (Wandersee et al., 1994, Gokhale, 1995, Lasry et al., 2008) that showed greater educational gains for students participating in active and collaborative learning than those receiving lectures.

It is interesting that, although students indicated they both liked and thought that they learned from lectures and tutorials about same amount, that most of the data showed that they learned better from tutorials. This could be interpreted as many of the students not really knowing how they learn best, which means that we, as instructors, are indeed right, and obligated to determine which pedagogies work best and to implement them, the data in this work showing that active & collaborative learning is indeed more effective than traditional lectures.

16.2 Assessment of Instructional Materials

Overall, the assessment results strongly support that when engaged in an activity students will learn more than when listening to lectures. During tests of all the instructional materials developed, students that participated in the activities showed greater gains than those that received lectures on the same topics. As shown in the analysis of the data for each individual activity, most of the differences were statistically significant. This was

shown for all trials of the *Solar System Walk* in Chapter 8, the *Comparative Planetology Activity* in Chapter 9, especially in the third trials and very strongly with the *visual tutorials* on comets and extra-solar planets in Chapters 10 & 11, where students doing the *visual tutorials* had not only greater gains on the *visual assessments*, initially, but also showed greater retention when taking them later when compared to students who received lectures on the topics. This was not as definitive, but still shown to be true in Chapters 12 and 13 for the Lecture Tutorials on planetary surface conditions and solar system formation. This verifies previous research on the use of LTs (Prather et al., 2005, Slater, 2008: see Pasachoff et al.) and the more general premise that larger learning gains will result when students are interacting and actively engaged. (Wandersee et al., 1994, Mazur, 1997, Hake, 1998, Bransford et al. 2000, Weimer, 2002, Donovan & Bransford, 2005, Lasry Et al., 2008)

Although in every case a specific activity does not always distinctly show better gains than a lecture on the same subject, it can still be concluded from this data and the previous literature support it, that most of the time, students that were engaged in active and collaborative pedagogies will show greater gains than those who are not. This combined with the above-mentioned affective-data that indicated that they enjoy and believe they are learning from the active and collaborative pedagogies at least as well as if not more than lectures, once again means that because it is indeed effective, we as instructors should be making every effort to teach our students in this fashion as much as possible.

16.3 Knowledge Centered Learning Environments

As indicated in Chapters 12 and 13 on the creation, implementation and assessment of LTs, the advantage they show over lectures when assessed could be due to the fact that they help create knowledge centered learning environments. These are learning environments where facts are not memorized, but used to teach concepts. This was likely true of the *Comparative Planetology* activity presented in Chapter 9 as well.

When students are engaged in working through the details of a process, such as the evolution of a planetary atmosphere, the formation of the solar system, or, as shown in Chapter 10, the changes in the head and tail of a comet that occur due to proximity to the Sun during its orbit, the facts become part of that process. The facts, when the head is larger or tail is longer or shorter or what direction it is pointing, *mean* something within in the conceptual framework, where the comet is relative to the Sun, rather than just being disjointed bits of information to be memorized. This is also true of planetary data, it become more than just facts to be memorized when used to put the objects of our solar system into different categories.

Both of these examples demonstrate exactly what is meant by a knowledge centered learning environment. The assessments of the examples of this learning environment provided in this work clearly show better student retention of both the concepts involved and the facts that support them than those of lectures about the same topics. These results show that a knowledge centered learning environment is indeed an example of an environment in which students are very likely to succeed.

16.4 Classroom Responders

During the first-run of testing of the planetary surface conditions and solar system formation LTs in Winter 2009, classroom responders were used *both* by sections that did the LTs *and* sections that received lectures on the topics for both diagnostic and formative assessment. As seen in the results (Chapters 12 and 13), the tutorial sections experienced greater gains on assessments than did the lecture sections, verifying the greater effectiveness of the LTs. During the next semester, Fall 2009, classroom responders were used *only* by the sections that did the tutorials, the purpose being to compare teaching with complete HPL pedagogy to teaching with lectures-only. As expected, the difference in gains between the two groups was even greater. This was also true for the *Comparative Planetology Activity* in Chapter 9. This was the only activity that did not initially show greater gains than lectures, although later tests did. The

increase in the difference between gains of the two groups is certainly not surprising and actually was expected. This is because the effectiveness of clickers themselves as a tool for active and collaborative learning is so well documented. (Duncan, 2006, 2007, 2008: see Pasachoff et al., Lasry et al., 2008, Mazur, 2009, Prather & Brissenden, 2009) This was also very evident in the pilot research project in Chapter 7. (LoPresto & Murrell, 2009)

There seems to be little question about the effectiveness of using classroom responders and the fact that students learn from them and enjoy when teachers use them. The affective data in Chapter 15 showed students citing as reason that they liked using clickers was they were a good way to review class material. Students perceived teachers who use “clickers” as being willing to take class time to review, something they indicated as very useful, that many teachers will *not* take the time to do. They were also considered by many as good preview of what test questions would be like.

Most positive reactions to “clickers” seems to be based on them being used as tools for formative assessments. This suggests that formative assessment may be when they are most effective. This also suggests that, when used in this capacity, classroom response systems can be an integral part of student success in active and collaborative learning.

16.5 Formative Assessments

Classroom responders were not used during instruction with the visual-tutorials on comets and extra-solar planets; rather, as discussed in Chapters 10 and 11, the visual components themselves were used as the assessments. Similar to the procedure with the LTs described above, during the Winter 2009 semesters, both sections doing the visual-tutorials and sections receiving lectures on the topics, were given the visual assessment both diagnostically and formatively. Also as shown in Chapters 10 and 11, sections doing the visual-tutorials out-gained the sections receiving lectures. Then in Fall 2009, as part of the evaluation of HPL pedagogy, only the sections doing the visual-tutorials were given the visual-assessment formatively and as expected the difference in gains between

these students and those in the sections receiving lecture-only increased. This result bodes well for diagnostic and especially formative assessment in general as an effective tool for learner-centered teaching and also verifies previous findings (Wilson & Sloane, 2000, Brissenden et al., 2002) especially when used in conjunction with “think-pair-share,” *TPS*, (Slater & Adams, 2003) or “peer-instruction,” *PI*, (Mazur, 1997, Greene, 2003, James et al., 2008) discussions during the formative assessment.

Once again, the data and supporting literature shows that whether it is done with classrooms response systems or in some other fashion, formative assessments of some type, by their very nature, since they allowing the student and the instructor to determine whether student understanding of a topic is correct and complete, while there is still time to react to the result and affect change is another very valuable component of active and collaborative learning.

16.6 HPL-Pedagogy

When diagnostic and formative assessments (including *TPS* or *PI* discussions) are used for instruction in conjunction with active and collaborative learning activities such as in the recommended use of *Lecture Tutorials* (Prather & Brissenden, 2009, *Lecture Tutorials*) this amounts to application of the HSLS-recommendations for effective science teaching (Donovan & Bransford, 2005) and employing the HPL principles and learning environments, (Bransford, 2000) or HPL pedagogy. When the students received diagnostic assessment, preconceptions were identified and could be dealt with. The activities developed were designed to be worked by students in groups, facts being used to teach concepts rather than to be memorized. Time for reflection on what was learned was given during formative assessments that occurred at the beginning of the next class period and included student discussion when necessary. All of the above clearly shows that the learning environments were learner, knowledge, assessment and community centered. Once again, assessment results from Fall 2009 clearly showed that gains by students taught with HPL pedagogy were much greater than those taught by traditional lectures alone. Since the effectiveness of all the activities used have been verified by assessments during the Winter 2009 semester and again during follow-up studies the

2010-2011 academic year, the Fall 2009 results verify the effectiveness of both the HPL principles and learning environments and the HSLS-recommendations.

All of this, which when put together amounts to making use of the HPL principles and learning environments, HPL pedagogy, and the HSLS recommendations for effective science instruction. Active and collaborative learning through the use of tested student-centered activities, be they LTs, visual tutorials or other exercises in conjunction with both diagnostic and formative assessment by classroom response systems/clickers or other methods that include “peer-instruction” and/or “think-pair-share” discussions, when applied to teaching introductory astronomy, are a “winning combination” that many instructors of introductory astronomy if they are not already should consider using.

16.7 The Hawthorn Effect, Instructor Bias and Teaching to the Test

The occurrence of Hawthorn Effect (Hake, 1998, from Slavin, 1992) is certainly possible and should not be dismissed. However, as discussed in Chapter 7 on the pilot research project, teaching with student-centered activities requires that the instructor circulate around the room and be available to answer questions and participate in discussions. Therefore, by definition, part of the advantage of these methods *is* giving student more individualized attention. (Hake, 1998) So, students in a learner-center environment will get more attention than those simply receiving lectures.

Also recall that the more assessments, in-class activities and discussions are done, the more different instructional methods are used, the more routine and commonplace they become to both the students and the instructor. So as a rule the Hawthorne Effect should diminish with time. (Hake, 1998) The instructors involved in teaching sections with learner-centered-techniques had been doing so for a number of years, so the methods were not new to any of them.

Precautions were also taken in all parts of the study to minimize instructor bias. Over the entire study data was taken with students taught introductory astronomy by five different instructors and whether the instructors were going to be lecturing or using learner-centered techniques discussions between the instructors occurred to make sure the concepts that were going to be assessed were still being covered. Also, perhaps more importantly, when two instructors were teaching multiple sections that were included in the study, each taught different sections by lecture and in a learner-centered fashion. The result being that students surveyed that were given lectures were not all hearing them from the same instructor and students receiving learner-centered instruction did not all have the same instructor either. Also, during the follow-up studies for each activity during the 2010-2011 academic year, *the author taught none of the sections assessed*.

When using the same questions for diagnostic and formative assessments and comparing gains of students in sections that did and *did not* receive the assessments as part of their instruction, there is a valid concern that there could be an increase in gains that are not necessarily from the different instructional pedagogies being tested, but rather from students repeatedly seeing the same or similar assessment questions, i.e. “teaching to the test.” As discussed in the pilot research study (Chapter 7) and in conjunction with the use of LTs (Chapters 12 and 13) this was considered possible, but likely not the main reason for the gains by the author of the SPCI (Bailey, 2008) and when testing the effectiveness of LTs (Prather et al., 2005). Also, when engaging in a study comparing lectures to active and collaborative learning, gains are expected to be better for students who participated in the latter, even if the lectures given were “teaching to the test.” (Prather, 2008)

16.8 Future Plans

Now that the primary instructional material of the *Solar System Unit* outlined in Chapter 6 have all been tested (Chapters 8-13) they will continue to be used in the introductory astronomy course at HFCC as a part of what has certainly been proven by this work as an example of the above-mentioned. “winning combination.”

All of the activities developed will undergo further testing and review as a continued part of the. (CATS projects / *Solar System Concept Inventory (SSCI) & Solar System Lecture-Tutorials Project*, <http://astronomy101.jpl.nasa.gov/cats/projects/>) As a result, some of them may then be adapted for inclusion in subsequent editions of *Lecture-Tutorials for Introductory Astronomy* (Prather et al., 2007) those that are not will be included in future editions of the new introductory astronomy text-book, *Fundamentals of College Astronomy* (LoPresto, 2010, 2011), that was written with pedagogy similar to that of this project, now, as of Fall 2010, being used at HFCC and at other institutions.

Fundamentals of College Astronomy (LoPresto, 2010, 2011) also includes tutorials on many topics in introductory astronomy outside the solar system “unit” that have been developed and assessed in fashions similar to those featured in this study. Continued assessment and revision of these activities is planned as well and the continued development and assessment of new learner-centered materials for subsequent editions of the text.

Continued participation in the CAE-CATS Solar System Project is planned through use of the *Solar System Concepts Inventory*, SSCI assessment instrument and well as the CAE-CAT Cosmology Project (CATS projects/ *Research on Students Beliefs and Reasoning Difficulties related to Cosmology* <http://astronomy101.jpl.nasa.gov/cats/projects/>) through the use an testing of recently development instructional and assessment of materials. (Wallace et al., 2011)

Other projects underway and planned may become part of the CAE-CATS Projects are; *A Life in the Universe Survey*, (LoPresto & Hubble-Zdanowski, 2012) a project to develop, validate and implement a survey that solicits students ideas about whether or not life exists elsewhere in the universe and if it could be contacted as well as what that life may be like. It has undergone initial development, validation and implementation at HFCC, but could be used regionally or nationally if distributed through the CAE.

Also, in the planning stages at this writing is a concept inventory on the observed motions of the stars and the Sun and their underlying causes. Likely it will be designed to compare the effectiveness of teaching the concepts with LTs to teaching them with lectures. There will also be the possibility of comparing groups that *all* do LTs, but with some sections receiving supplementary instruction through lecture with others receiving it via planetarium.

A small part of Chapter 11 was devoted to a computer version of the visual tutorial assessment on extra solar planets. Another project being considered is the assessment of gains by students using more computer-based activities (LoPresto, 2011) in both traditional “in class” or “on ground” and online astronomy instruction. This could eventually lead to assessments developed to compare the gains of students taking an entire astronomy course online to those taking courses in the classroom.

As discussed at the end of Chapter 11, the research on visual assessments and tutorials discussed in Chapters 10 and 11 show early promise as an active and collaborative pedagogy for introductory astronomy instruction. Development and testing the effectiveness of more of these designed for other topics, again including some outside the solar system unit, is another project worth of consideration.

It should be noted that visual assessment and tutorials discussed in Chapters 10 and 11 are perhaps the specific pedagogies most unique to this work. Although they are implemented in a similar fashion to lecture tutorials, the use of the visual components in the activity as both diagnostic and formative assessments is unique. Although the idea of students walking through solar system model is certainly *not* unique, Chapter 8 of this work and the resulting publication were an original example of assessing student learning from such an experience. The “*Comparative Planetology Activity*” presented in Chapter 9 was author’s very first attempt at using active and collaborative learning in the classroom. Though inspired by a chapter in the first textbook he ever taught astronomy from (Kuhn, 1989) it was also original

Research subsequent to this study that has been suggested by the members of the authors committee include, attempting to assess the performance of students of differing demographics, such as age group, ethnicity or gender in active and collaborative learning environments. Also attempting to determine *why* particular items in a multi-item assessment may favor students who were lectured to or those that were taught by other methods. And finally determining specifically if certain aspects of active and collaborative learning, being engaged in an activity, the activity type, or working in groups, is most responsible for the apparent success of the methods,

Perhaps the most important question for continuing research is, *why* these different aspects of active and collaborative learning work as well as they do? Once it is accepted that student conceptual gains will indeed be higher with active and collaborative engagement, the next logical question to ask is “why” this is true? The simple argument is that students will understand concepts and retain the facts that support them better when they actively work with the ideas rather than just being told about them, but that explanation, the success of a knowledge centered environment given above, may not really go much further beneath the surface than the results of the research that shows this to be true.

Going by the adage that the results of any satisfactory research should bring up at least as many good questions as it answers, makes attempting to determine the underlying reasons *why* active and collaborative learning seems to work better for many students than passively listening to lectures an important part of the next steps to be taken in the research on teaching and learning and specifically the teaching and learning of science and introductory astronomy.

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Appendices

Appendix 8.1

The HFCC Solar System Walk

The Sun's Display case is located on the Eastern most side of the planetarium's circular wall, on the top floor of the science building.

1. The sun appears to be about the size of a (circle one);

Golf ball Baseball Softball Basketball

Use the map in the sun's display case to find the all the inner solar system (Terrestrial) planets.

2. The Terrestrial Planets all appear to be the about the size of a (circle one);

head of a pin small marble golf ball a baseball

3. About how far from the sun did you find Earth (circle one)?

3 inches 3 feet 30 feet 300 feet

Now use the maps in the display cases to begin your venture into the outer solar system, But first do not forget to cross the asteroid belt!

4. The asteroids appear to be about the size of (circle one);

Small marbles the heads of pins specs of dust or gains of sand

They are so small they are microscopic!

5. Once you have found Jupiter, it appears to be about the size of a (circle one)'

baseball golf ball large marble head of a pin

6. About how far is Jupiter from the Sun (circle one)?

15 feet 50 feet 150 feet 1500 feet

Make sure to visit all the outer solar system (Jovian) planets.

7. Name in order the next three planets you visited;

8. The Jovian Planets are all about the size of a (circle one);

baseball golf ball large or small marble head of a pin

Now finish your trip by finding Pluto.

9. Pluto's size is most similar to a (circle one);

Terrestrial planet Jovian planet (an) asteroid

In between an asteroid and a terrestrial planet.

10. About how far from the Sun is Pluto (circle one)?

A few tens of feet A few hundred feet The better part of a mile Miles away

Something to think about-In the real solar system the space between the planets is NOT crowded with all the things you see on campus. Rather; interplanetary space is virtually empty, that is why we call it space!

An afterthought-Also, since our campus represents a solar system, it is reasonable to say that the next solar system over, with nothing between our solar system and the next (interstellar space) would be another campus, where do you think this campus might be?

Next Door Detroit Ann Arbor Chicago Arizona

British length units, ft. and miles, were used instead of S.I. units in both the worksheet and assessment because whether we like it or not, these are still the units in which most of our students have been trained to think. It was felt that using meters and kilometers as distance units had the potential of confusing many students and becoming a variable in incorrect responses.

Appendix 9.1

Comparative Planetology

1. Plot bar-graphs comparing each of the following categories of data for all of the planets;

Radius, Mass, Density, Distance from the Sun, Orbital Period, Rotational Period, Number of Moons

Each group of students will be assigned ONE bar graph to plot

2. Examine the bar graph comparing the **Radii** of the planets, which planets seem large?

Which planets seem small?

3. Examine the bar graph comparing the **Mass** of the planets, which planets are heavier?

Which planets are lighter?

4. Examine the bar graph comparing the **Density** of the planets, which planets seem more dense?

Which planets seem less dense?

What does density tell you about a planet?

5. Based on the comparisons you have made, have any planets been grouped together every time?

How many groups are there?

Which planets are in which groups?

6. Examine the bar graph comparing the number of moons orbiting each planet. Which planet group's members have many moons?

Which planet group's members have few (or no) moons?

On what does the number of moons orbiting a planet likely depend?

7. Examine the bar graphs comparing the distance of the planets from the Sun.

Which planet group is closer to the Sun?

Which planet group is further from the sun?

8. Examine the bar graph comparing the rotational periods of the planets, which planet group rotates faster?

Which group rotates slower?

What do you think the negative-signs mean?

9. List the members of each of your planet groups.

List what properties from the bar graphs that the planets in each of your groups have in common.

In general, how do the properties that you listed differ when compared between the different planet groups?

10. Is (are) there a (any) planet(s) that *do not* seem to fit into a group?

Have you heard about a recent decision made about this object?

Did this exercise help clarify the decision for you?

Do you agree with the decision? Why or why not?

Appendix 10.1

Comets

Comets are asteroid –sized chunks of rock and ice that come from the far outer solar system to the inner solar system in extremely eccentric orbits. For much of their orbit, they remain as these small rocky/icy comet *nuclei*, but when they get to the inner solar system, close to the sun, where temperatures are higher, they become very interesting.

The ice begins to vaporize, which forms an envelope of gas around the nucleus, called the *coma* (or head of the comet). *The closer the comet gets to the sun, the larger the coma will be!*

Material, both gas from the coma and dust from the rocky portion of the nucleus begin to stream away from the nucleus, forming both a gas and a dust *tail* on the comet. *Since the tails are caused to form by the sun's rays, they will always point in the direction opposite the sun!*

1-**Figure 1** shows the portion of a comet's highly eccentric orbit that is close to the sun. At each numbered position of the comet's *nucleus* draw the comet's *coma* (head) and *tail*. *Make sure that your drawing clearly shows any differences between the size of the coma and length of the tail and the direction the tail is pointing.*

2-List the position numbers in **Figure 1** in order from the smallest to the largest size of the *coma* (head).

3-List the position numbers in order from shortest to the longest length of the *tail*.

4- For each numbered position in **Figure1**. Choose which arrow in **Figure 2** best represents which way in space the comet's tail will be pointing.

Position 1	A	B	C	D	E
Position 2	A	B	C	D	E
Position 3	A	B	C	D	E
Position 4	A	B	C	D	E
Position 5	A	B	C	D	E

Figure 1

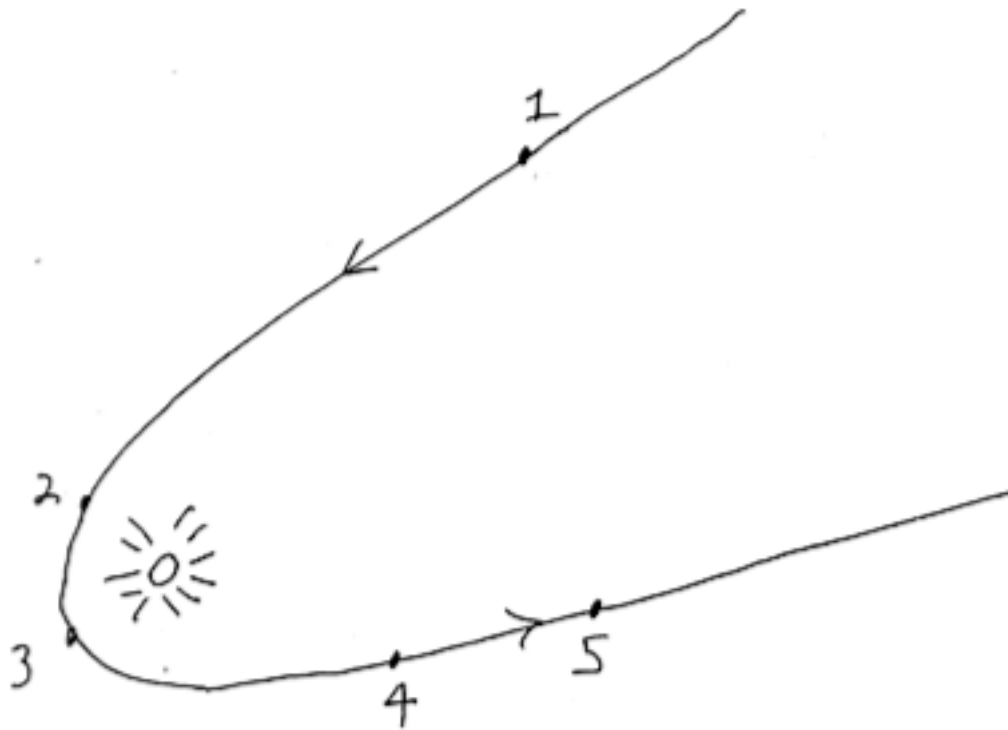
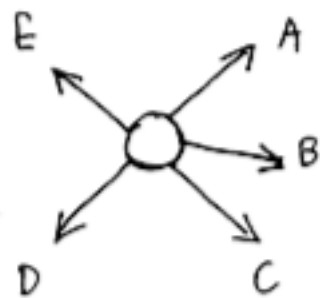


Figure 2

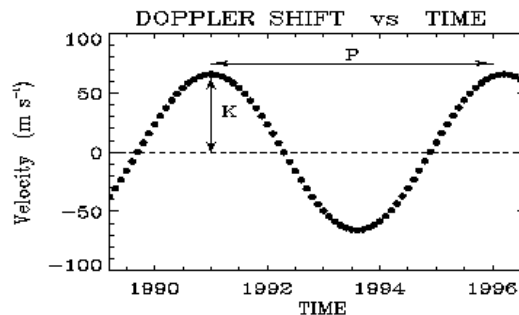
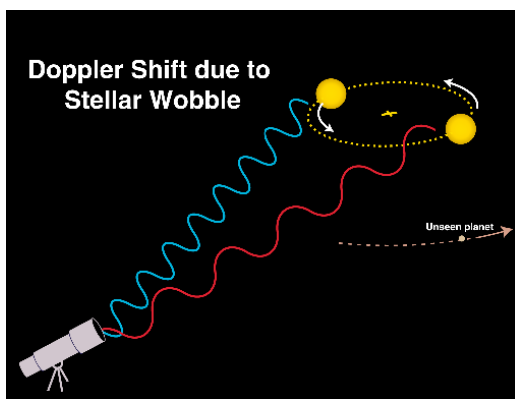


Appendix 11.1

Extra Solar Planets

When one object orbits another, the less massive object does not actually orbit the more massive one, they both orbit the center of mass between them. This is a point that is as many times closer to the more massive object as the amount of times more massive the object is. For instance, our Sun is 1000 times more massive than Jupiter, so our Sun and Jupiter both orbit a point between them that is 1000 times closer to the Sun.

If a planet is massive enough it will cause its star to move in an orbit large enough that the motion can be observed from Earth with the Doppler effect.



As the star orbits the center of mass between the large planet and itself a blueshift in its light will be noticed when the star is moving toward Earth and a redshift when it is moving away. The Doppler shifts will alternate from, a maximum blueshift, to a maximum redshift and back to the maximum blueshift in a time equal to the stars orbit, which is *equal to the orbital period of the planet*.

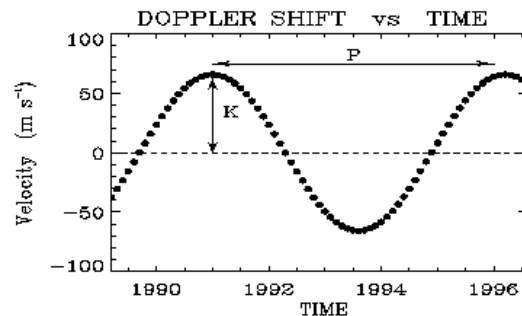
Once the orbital period of the planet is known, the planet's *orbital distance* can be immediately determined from Kepler's third law, then the *mass* of the planet can be calculated from Newton's theory of gravitation.

Using this **Doppler Detection Method**, we can determine the orbital period, orbital distance and mass of planets in orbit of distant stars that we otherwise cannot even see!

Part 1

Data determined from the Doppler-shifts caused by planets orbiting the three stars [HD 46375](#), [HD 16141](#), and [HD 195019](#) is recorded in the table below.

Star	Mass (Jupiters)	Orbital period (days)	Orbital Distance r (AU)	Maximum Doppler-shift K (m/s)
HD 46375	0.25	3	0.04	34.5
HD 16141	0.25	76	0.35	11.3
HD 195019	3.6	18.2	0.14	271



The horizontal variations (the back and fourth) on the graph measures *time*, so the horizontal variations on a graph are most likely more affected by the planet's (circle one);

mass

distance from the star

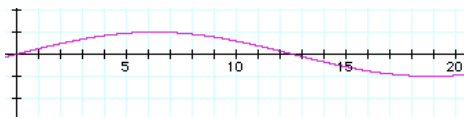
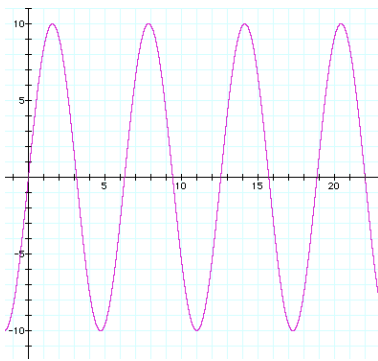
Looking at the data, the amount of Doppler-shift (labeled K on the data table and graph) caused by the planets (the vertical variation, the up and down on the graphs) seems to be *most* affected by

mass

distance from the star

Now based on the answers you just gave and the values on the table;

Label each of the three graphs below with the name of the star from the table that is most likely to represent the Doppler-shift variations caused by its planet.



Based on your choices above;

Stars that show larger Doppler-shifts (K-value) (up and down on the graph) probably have planets that are (circle all that you think apply):

More massive

Less massive

In closer orbits

In farther orbits

Stars with a more rapid repetition in the variations of their Doppler-shifts (back and forth on the graph) probably have planets that are (circle all that you think apply);

More massive

Less massive

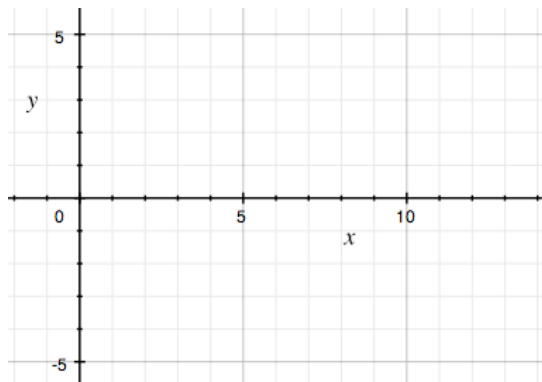
In closer orbits

In farther orbits

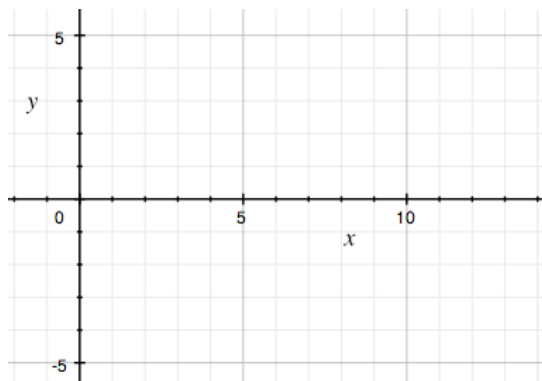
Now, Based on what you have learned;

Draw the Doppler-shift graphs caused by each of the planets described below
(ignore the numbers on the axes);

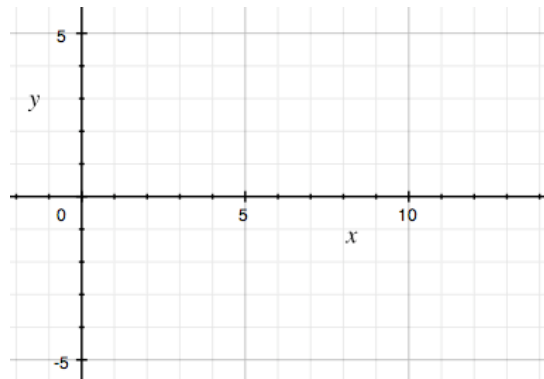
A more massive planet is a farther orbit



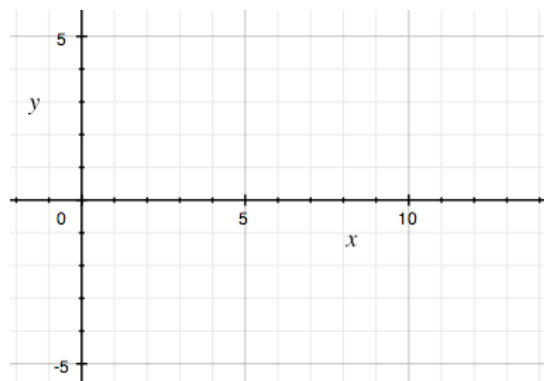
A more massive planet in a closer orbit



A less massive (lighter) planet in a farther orbit



A less massive planet in a close orbit.



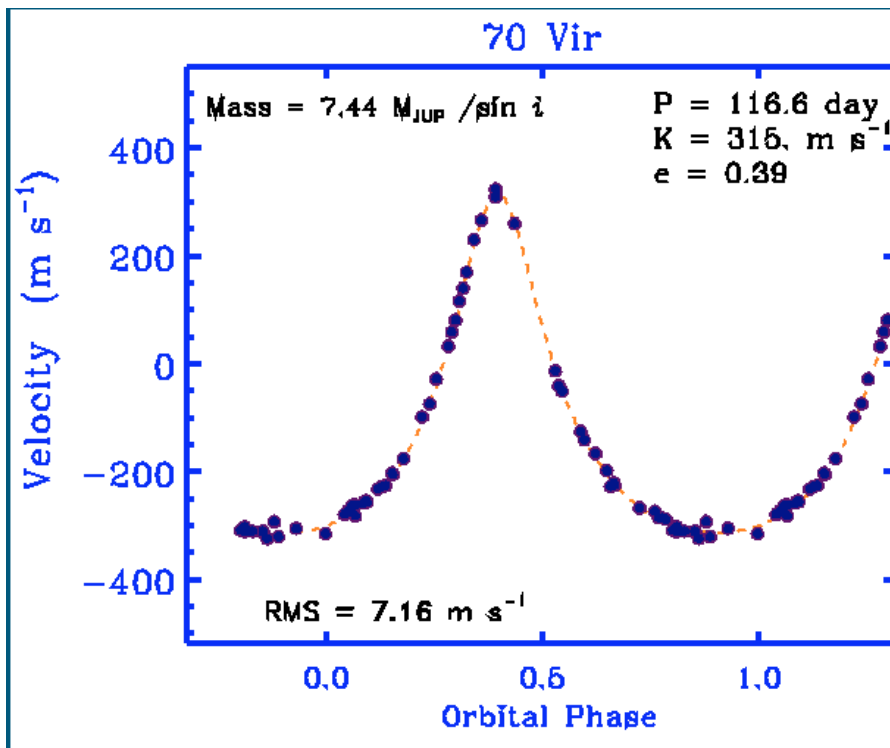
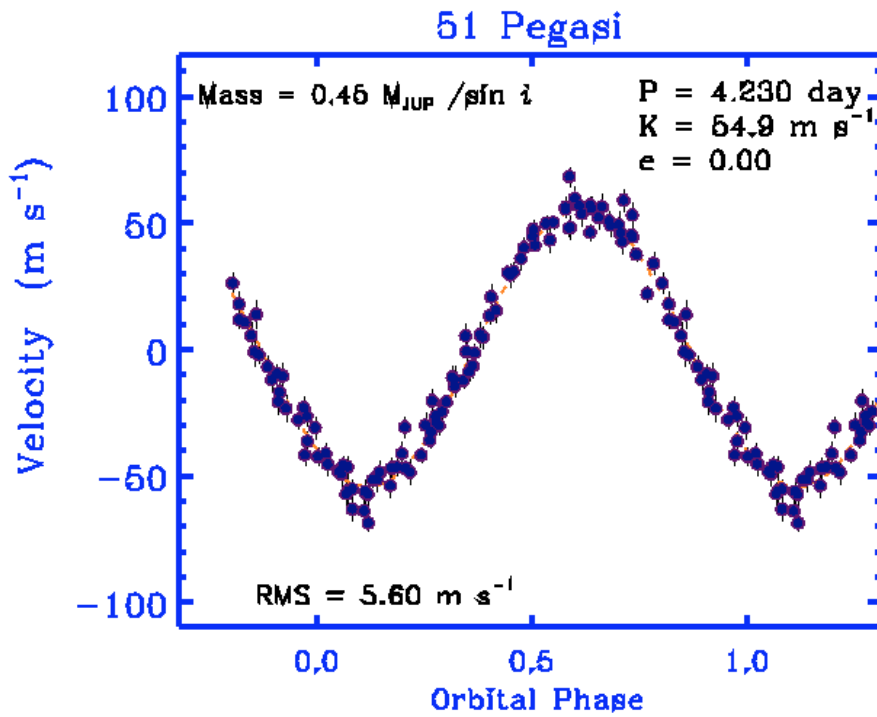
Part 2

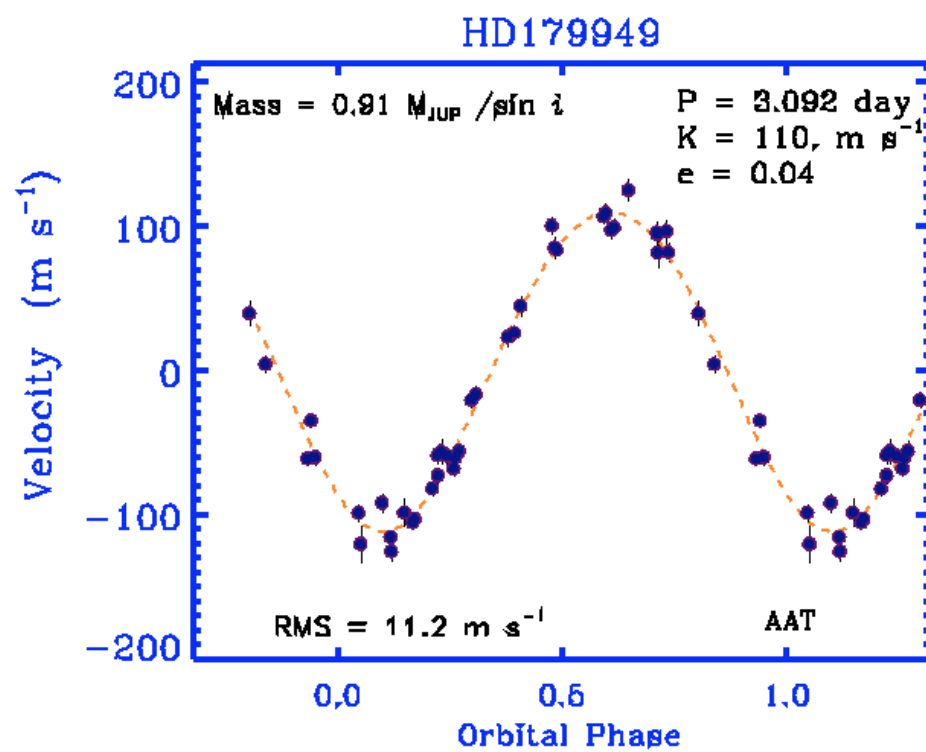
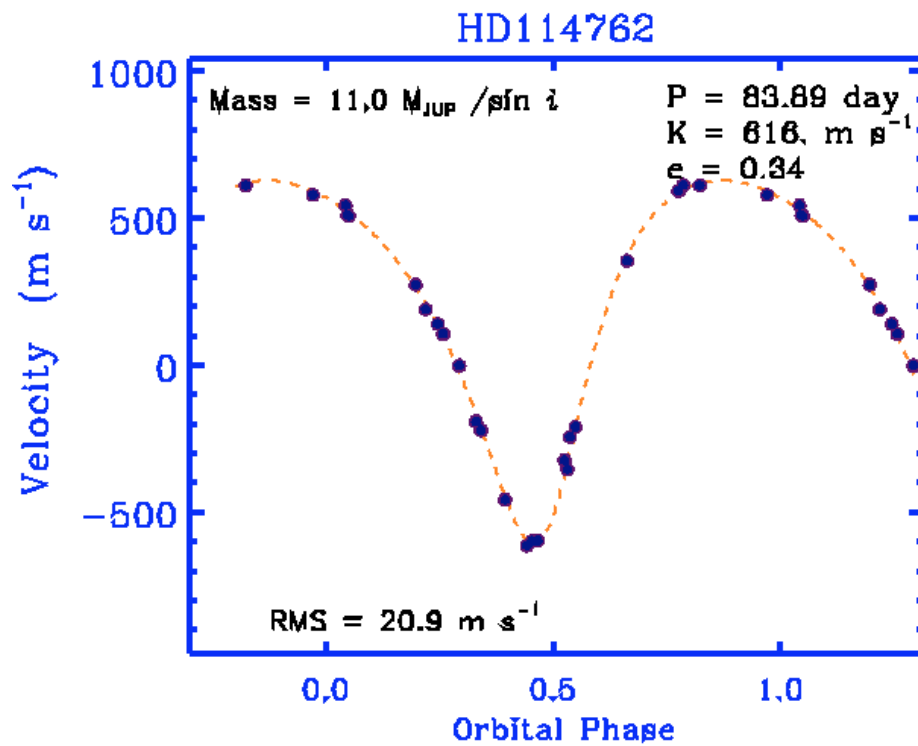
The eccentricity of an orbit is a measure of how elliptical or how far it is from being circular. More circular orbits have low eccentricity orbit (close to 0) and more elliptical orbits have higher (0.2 or higher) eccentricity.

In the space below draw a star and the path of a planet orbiting the star in a *low* eccentricity orbit.

In the space below draw a star and the path of a planet orbiting the star in a *higher* eccentricity orbit.

Now examine the Doppler-shift graphs below and note the waveforms and the orbital eccentricities (e)

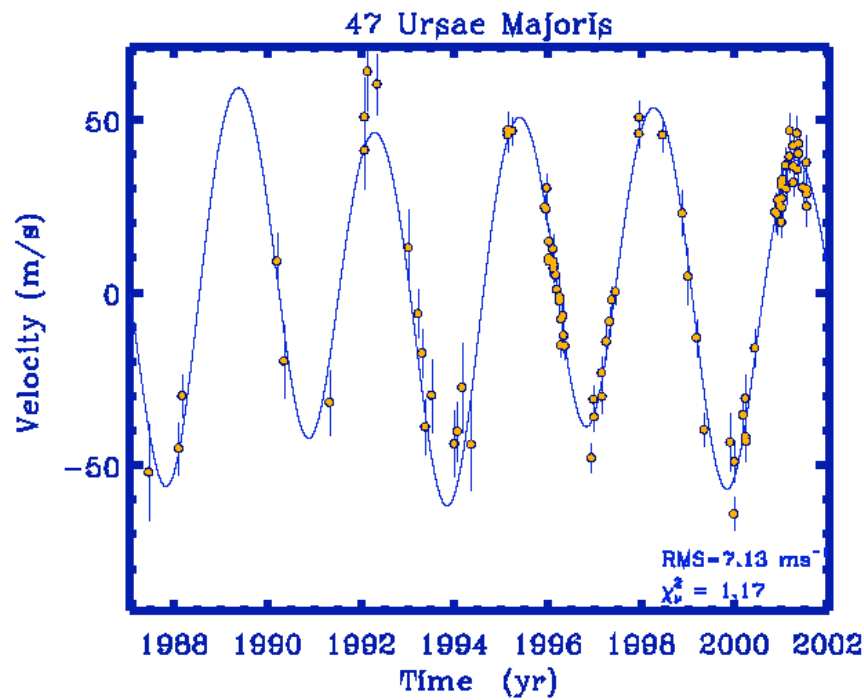
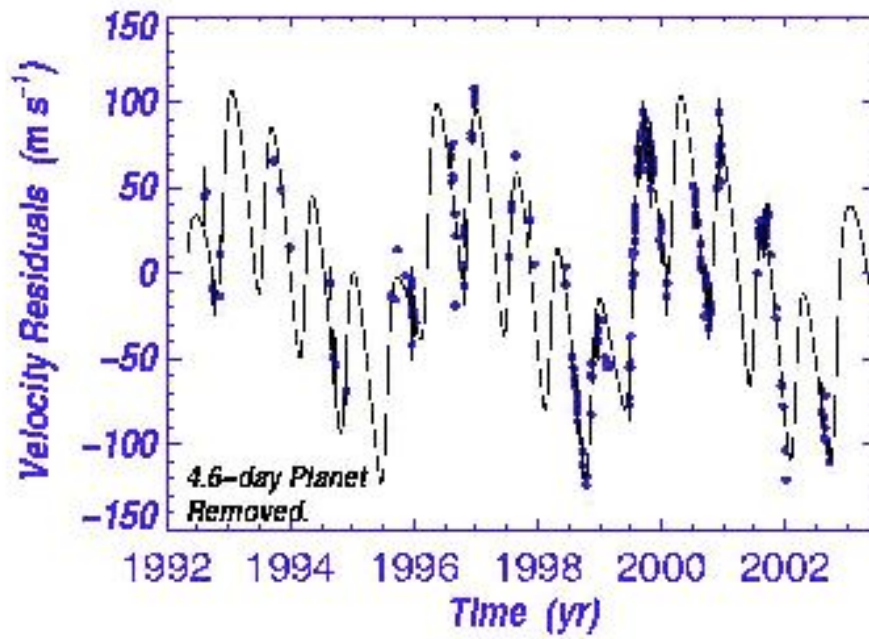


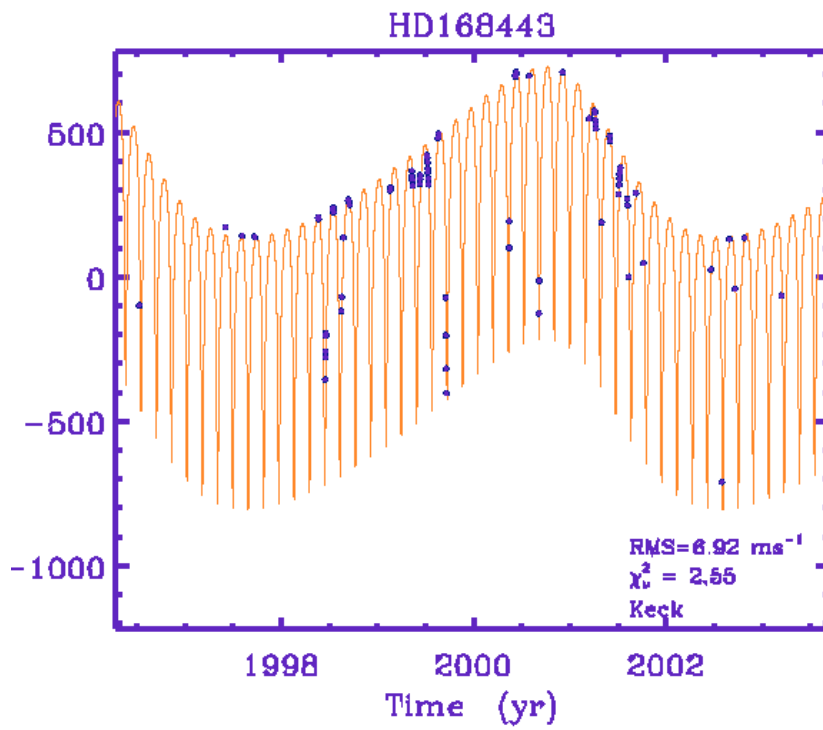
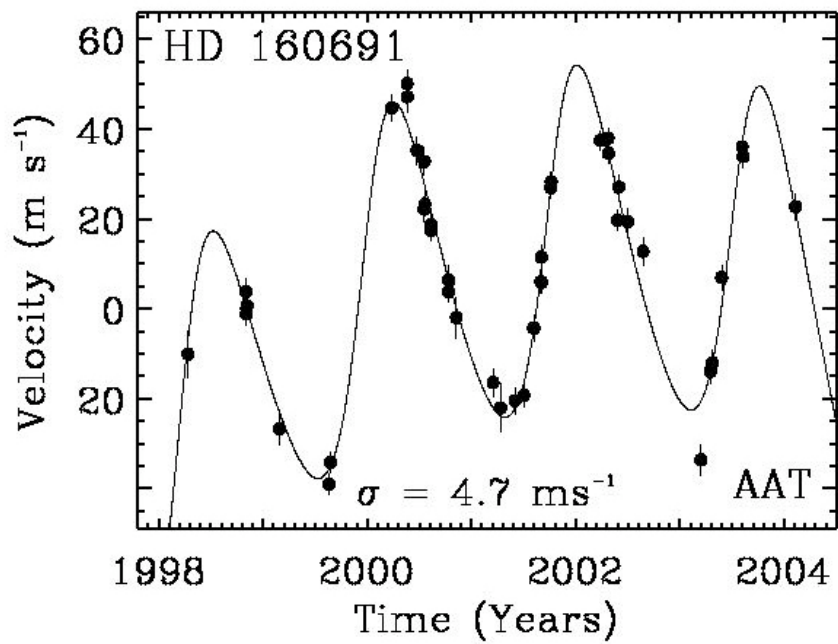


What difference did you notice in the waveforms of the above Doppler-shifts plots of the low (close to 0) and higher (0.2 or higher) eccentricity orbits?

Part 3

Below are several Doppler-shift graphs from stars that have multiple planets in their systems.

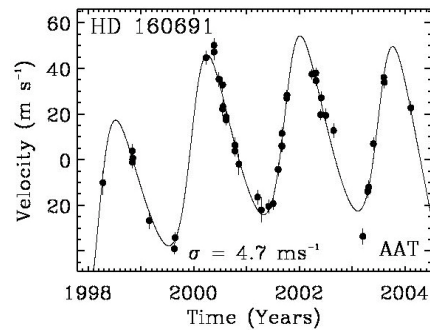
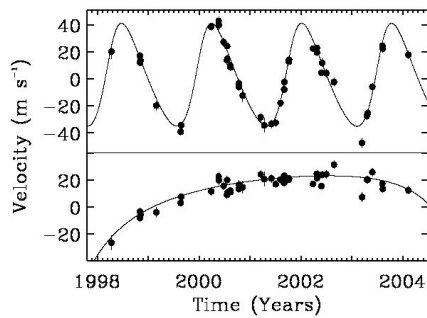




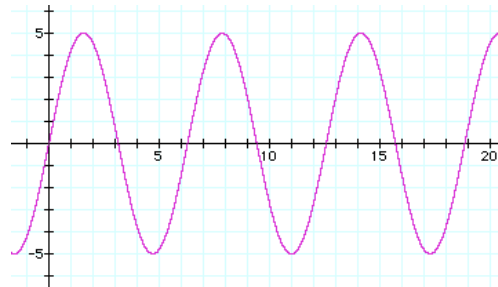
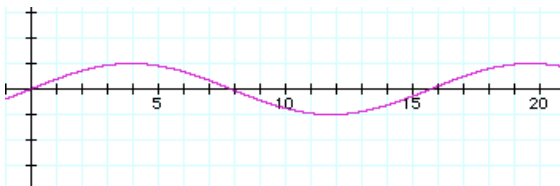
How do these plots seem to differ from those you have seen for stars with only single planets in orbit?

Single planets will result in Doppler-shift variations that repeat in the form of a simple waves but when more than one planet is present the combination of multiple Doppler-shifts of different amount and period creates a more complicated or compound waveform.

For instance; the graphs below; the one on the left is for two individual planets, the one on the right is for their combination.



Below are Doppler-shift graphs for two individual planets of a multiple system.



Which planet is further from the star?

left / right (circle one)

Which planet has a greater mass?

left / right (circle one)

Appendix 12.1

Surface Conditions of Terrestrial Planets

1-Compare the four planets Mercury, Venus, Earth and Mars and name two obvious (simple) factors that could affect surface conditions on these planets.

[Note- either pictures or models of the planets can be shown as long as they are in their correct *order* from the sun and show the correct relative *sizes*]

Part 1-Planetary Geology

2-Use the pictures of the planetary surfaces provide to fill in *yes/no* for each process on each planet.

Table 1- Processes affecting the surface of Terrestrial Planets

Process	Mercury	Venus	Earth	Moon	Mars
Cratering (from impacts)				yes	
Geology (tectonics & volcanism)				no	
Erosion (wind & weather)				no	

[Note- either pictures could be shown or in the interest of time the table could be presented already filled in-what is important is that the student used the data to draw conclusions]

3-Based on the data in **Table 1**, what seems to be the relationship between the *size* of a planet and whether or not there is geological activity (tectonics and volcanism)?

4-Based on the data in **Table 1** does the *distance from the sun* (and therefore the *surface temperature*) seem correlated with geological activity?

5- The surfaces of the Moon and Mercury are very similar, they are covered with many impact craters and have few other surface features.

This suggests that size / surface temperature (circle one)

is a *more important* factor in determining whether or not a planet will have geological processes occur.

Explain your choice.

6-The more massive a Terrestrial planet, the more internal heat it will have left over from its formation to drive geological activity.

Based on this statement and considering the fact that we know that geological activity is still occurring on Earth;

Match each planet below with the current state of its geological activity (you will obviously have to use one choice on the right more than once);

Mercury	Has had little or no geological activity
Venus	Has had geological activity in the past
Mars	May still be geologically active
Earth's moon	

Part 2-Planetary Atmospheres

Table 2-Planetary Atmospheric Data

Planet	Surface Temperature	Atmospheric Composition	Atmospheric Pressure
Mercury	100-620 K (night-day)	none	0 (none)
Venus	750K	96% CO ₂ ; 3.5% N ₂	90 (very thick)
Earth	300K	78% N ₂ ; 21% O ₂	1 (thick)
Earth's Moon	100-400 K (night-day)	none	0 (none)
Mars	218K	95% CO ₂ ; 2.7% N ₂	1/90 (thin)

1-What *basic* factor (from **Question 1** in **Part 1**) likely has the most affect on the surface temperature of a planet?

Distance from the Sun / Size of Planet (circle one)

2-Again, what *basic* factor (again from **Question 1** in **Part 1**) is most likely responsible for the pressure (or thickness) of an atmosphere or, whether or not a planet even has an atmosphere? Hint-Gravity is what holds atmospheric gases around the surface of a planet.

Distance from the Sun / Size of Planet (circle one)

3-When a planet first forms, the gases released when the surface cools from a molten to a solid state (a process known as *volcanic degassing*) become its initial atmosphere, these gases are Carbon-dioxide-CO₂ Water-Vapor-H₂O and Nitrogen-N₂.

Match which of these original three gases released during degassing are currently most abundant (see **Table 2**) in the atmospheres of each of the Terrestrial planets (again, you will have to use choices on the right more than once);

Mercury	Water Vapor (H ₂ O)
Venus	Carbon Dioxide (CO ₂)
Earth	Nitrogen (N ₂)
Mars	None
Earth's moon	

4-Where did all the water vapor go?

As Earth cooled, what do you think would have happened to most of the water vapor from Earth's original atmosphere?

Hint-What currently covers about 2/3 of Earth's surface?

As Mars cooled, what do you think would have happened to most of the water vapor from Mars' original atmosphere?

How do you think the cooling of Venus compared to the cooling of Earth and Mars?

As Venus cooled, what likely DID NOT happen to the water vapor in Venus's atmosphere that DID happen to it on Earth?

Where do you think Venus' water vapor went? Hint, carbon dioxide is a MUCH heavier gas than water vapor.

5-Where did the carbon dioxide go?

Liquid water is a "sink" for carbon-dioxide meaning that liquid water absorbs carbon dioxide.

Based on this, which Terrestrial planet would you expect to have the least carbon dioxide in its current atmosphere?

How else could carbon dioxide be taken out of the atmosphere of this planet?

Hint-Looking again at **Table 2**, what *non-original* gas seems to have “replaced” much of the carbon dioxide?

Where might this gas come from?

Which Terrestrial planet seems to have the atmosphere that is most “evolved” or the atmosphere most changed, from its original state?

6- *Too hot, too cold, just right.*

Carbon dioxide is an important “*greenhouse-gas*.” Carbon-dioxide molecules absorb heat that has been re-emitted by a planet after the planet has absorbed energy from the sun. The “*greenhouse-effect*” is the natural way that a planet heats its atmosphere.

Based on atmospheric data (see **Table 2**) which planet might you expect to have the most greenhouse effect and therefore be the hottest?

Based on atmospheric data (see **Table 2**) which planet might you expect to have the least greenhouse effect and therefore be the coldest?

What is the reason for the atmospheric conditions of Earth's Moon and Mercury (recall them from **Table 2**)?

Write the name of the Terrestrial planet that best fits each description of the amount of greenhouse effect in its atmosphere.

Too much-

Just the right amount-

Not enough-

None at all-

Write the name of the Terrestrial planet that best fits each description of its atmospheric temperature.

Too Hot-

Too Cold-

Just Right-

What environmental problem does Venus' atmosphere make you think about?

Part 3-Review Questions

1. What is the main factor (s) that affect (s) the amount and duration of geological activity on a terrestrial planet?
2. What is (are) the main factor (s) that affect (s) atmospheric conditions on a terrestrial planet?
3. The moons of the giant Jovian planets are small rocky-metal bodies that are, at the largest, about the size of Mercury (but most are smaller). Based on this and what you have learned about the factors that affect geological activity and atmospheres on similar objects (Terrestrial planets), what geological and atmospheric conditions would you expect to find on the surface of a typical *Jovian* moon?

Appendix 13.1

Formation of the Solar System

The Sun is thought to have formed when material at the center of a giant cloud of gas and dust called a *nebula* gravitationally pulled together. When this *protosun* gathered enough material, it became massive enough to exert tremendous pressure on its core. This raised the temperature high enough for nuclear fusion to occur there. This produced the energy necessary for the sun to begin to shine, or more simply, to give off light and heat to its surroundings, the leftovers of the original nebula or the Sun's solar-nebula. This *solar-nebula* was the material from which the planets of our solar system would form.

	Metals	Rock	Hydrogen Compounds	Gases
Examples	Iron, nickel, Aluminum	Various Minerals	Water, methane, ammonia	Hydrogen, Helium
Condensation Temperatures	1,000-1,600 K	500-1,300 k	< 150 K	DO NOT condense in Nebula
Relative Abundance	0.2%	0.4%	1.4%	98%

Table 1-Condensation Temperatures of materials in the solar nebula

1. How would you expect temperatures in the solar nebula to vary with increasing distance from the sun?

Does **Table 2** agree with what you expect?

Does **Figure 1** agree with what you expect?

2. As the solar nebula cooled, parts of it cooling to as low as 500 K, which of type (s) of materials of those shown in **Table 1** would you expect to condense (become solid) out of the solar nebula first?

Distance from Sun (AU)	Temperature (Kelvin)
0.2	2000
0.5	1000
1	500
2	300
5	150
10	100
20	50
50	20

Table 2- Temperatures in the solar nebula at different distances from the Sun.

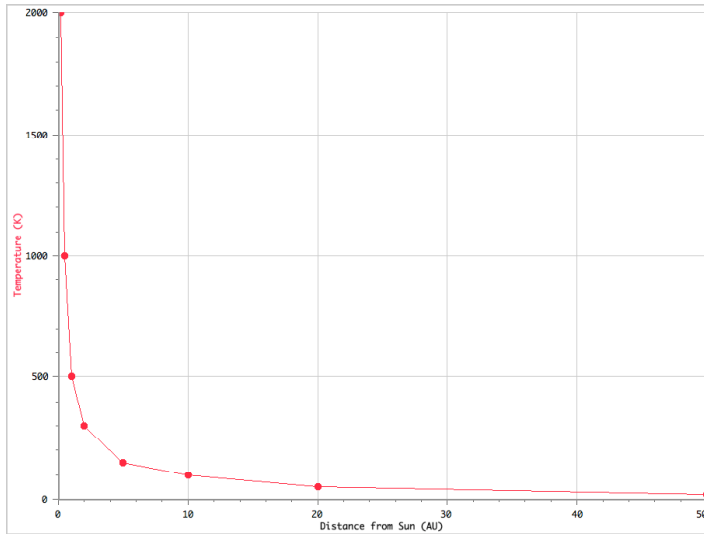


Figure 1-Plot of Temperature in the Solar Nebula vs. Distance from the Sun.

Note-In early versions of this tutorial, students were asked to use the data in Table 2 to plot the graph themselves, but as with the plots of the histograms in the *Comparative Planetology* activity in chapter 9, this was causing the tutorial to run longer than intended and as can be seen in Item 1 in Tables 12.6.1 and 12.6.2 below, pretest scores on this concept were already quite high.

These materials began to gravitationally pull together and form larger object called *planetisimals*. The *planetisimals* then formed planetary seeds or *protoplanets*.

3. About how far from the sun would be the *closest* distance that any of the materials from question 2 could condense (see **Table 2** and **Figure 2**)?

This distance is called the ***rock-metal condensation line***.

4. Can any of the materials in **Table 2** condense inside (closer to the sun than) the rock-metal condensation line?

Therefore can planets form inside this line?

5. About how far from the sun would you expect temperatures to cool down as low as 150 K or less (again see **Table 2** and **Figure 2**)?

This distance is called the *frost line*.

6. What materials in **Table 2** could then condense (become solid) on the already formed *protoplanets* beyond the frost line, creating a second layer of material on these objects?

What *common* name do we give to these materials when they condense on something (remember- they are beyond the frost line)?

7. So now, where relative to the sun, are larger objects found?

Where are smaller object found?

Where are no objects at all found?

8. Which materials in **Table 2** *will not* condense (will not become solid) anywhere in the solar nebula? Why won't they?
9. Which planetary objects, the larger or smaller ones, are now likely to collect large amounts of the remaining uncondensed gases from the solar nebula? Why?

Can you give another reasons that this is the case?

HINT-Keep in mind that temperature is a measure of the energy of molecular motion, so molecules in warmer regions are moving much faster that those in cooler regions.

10. Now, describe the smaller objects that have formed;

Of what materials are they mostly composed?

Where did they form relative to the sun and to the larger objects?

In how many layers (or steps) did they form?

What type of planet that you are familiar with are these?

11. Describe the larger objects that have formed.

Where did they form relative to the sun and to the smaller objects?

In how many layers (or steps) did they form?

What type of planet that you are familiar with are these?

12. Which type of planet is more evolved (has gone through more steps in its formation)?

13. Based on the investigation you have just undertaken;

What is the single most important factor in determining what kind of planet will form at a given location?

What controls this factor?

14. Many smaller objects that condensed from the solar nebula, are leftovers that did not become part of a planet

Of what would small objects that formed closer to the sun be made? What do we call them?

Of what would small objects that formed farther from the sun largely be made? What do we call them?

15. What do we call objects that are likely to collide with other objects?

How do you think the numbers of collisions that would occur would change over time? Explain your answer.

What might we call objects that are captured into the orbit of other larger objects (planets)?

Appendix 14.1

The Solar System Survey

1. Which is NOT considered an Earth-like (or *Terrestrial*) planet, a planet with enough properties similar to Earth to be considered the same type of planet?
 - a. Mercury
 - b. Venus
 - c. Mars
 - d. Pluto
 - e. [All of the above ARE considered Terrestrial planets]

2. Which is NOT a property of the Earth-like planets of our solar system when compared to the other type of planet?
 - a. Smaller and less massive
 - b. Closer to the sun
 - c. More rocky and metallic composition
 - d. Lower density
 - e. [All of the above ARE properties of Terrestrial planets]

3. Which IS (are) considered Jupiter-like (or *Jovian*) planets, planets with enough properties similar to Jupiter to be considered the same type of planet?
 - a. Saturn only
 - b. Uranus and Neptune
 - c. Saturn, Uranus and Neptune
 - d. Saturn, Uranus, Neptune and Pluto
 - e. [None of the above; Jupiter is in a class by itself]

4. Which IS a property of the Jovian planets of our solar system when compared to Terrestrial planets?
- a. Low densities
 - b. Farther from the Sun
 - c. High mass
 - d. Ring systems
 - e. [All of the above]
5. Why is Pluto no longer considered a planet?
- a. Its orbit
 - b. Its composition
 - c. It does not fit into the major planet categories
 - d. [It is actually only one of a group of many objects of similar size, composition and orbit; so all of the above]
 - e. [Actually, since its mass is solid, Pluto is considered one of the Terrestrial Planets]
6. How did temperatures in the solar nebula (the material from which the planets formed) vary with distance from the sun?
- a. Temperatures got higher with increasing distance from the sun.
 - b. Temperatures got lower with increasing distance from the sun.
 - c. Temperatures remained about constant at all distances from the sun.
 - d. [None of the above; temperatures varied in a random fashion]
7. The cores of the Jupiter-like planets are probably;
- a. mostly solid and about the size of a Terrestrial planet.
 - b. mostly liquid and about the size of a Terrestrial planet core.
 - c. mostly gas and about the size of a Terrestrial planet.
 - d. mostly ice and about the size of a Terrestrial planet core.

8. The determining factor in which kind of planet will form at a given location seems to be _____ which is controlled by _____.
- a. distance from the sun; temperature
 - b. temperature; distance from the sun
 - c. [distance from the sun only]
 - d. [temperature only]
9. Which is a correct list of the likely compositions of the different layers of a Jovian (Jupiter-like) planet going outward from the center?
- a. solid, liquid, gas
 - b. liquid, solid, gas
 - c. gas, liquid, solid
 - d. solid, gas, liquid
 - e. liquid, gas, solid
10. Which type of planet is more evolved (changed); which has gone through more steps in their formation?
- a. Terrestrial (Earth-like)
 - b. Jovian (Jupiter-like)
 - c. Both types have gone through similar changes
 - d. Neither type has gone through any changes since the initial step in their formation.
11. Which is a correct list of the different types of planets that form in different regions of the solar system in an order going outward from the Sun?
- a. None, Terrestrial, Jovian
 - b. None, Jovian, Terrestrial
 - c. Terrestrial, None, Jovian
 - d. Jovian, Terrestrial, None
 - e. [None of the above, different planet types can form in any region]

12. What do we now call the leftovers from the solar nebula after planetary formation, the material that did not become part of a planet?

- a. Asteroids
- b. Comets
- c. Meteoroids
- d. [Any of the above]
- e. [None of the above-the leftovers were blown away by the solar wind]

13. Which process (es) is (are) involved in shaping the surface of a terrestrial planet?

- a. Cratering
- b. Tectonics
- c. Volcanism
- d. Erosion
- e. [All of the above]

14. Which factor(s) is (are) important in determining the amount and duration of geological activity on a terrestrial planet?

- a. Distance from the sun
- b. Surface temperature
- c. Size of the planet
- d. [Both a and b above]
- e. [All of the above]

15. Which factor(s) is (are) important in determining whether or not a terrestrial planet has an atmosphere and the conditions (composition, thickness etc.) of the atmosphere?

- a. Distance from the sun
- b. Surface temperature
- c. Size of the planet
- d. [Both a and b above]
- e. [All the above]

16. Which is a correct list of the terrestrial planets in order of increasing atmospheric pressure (from the thinnest to the thickest atmosphere).

- a. Mercury, Venus, Earth, Mars
- b. Venus, Mercury, Earth, Mars
- c. Earth, Venus, Mars, Mercury
- d. Mercury, Mars, Earth, Venus
- e. Mars, Earth, Venus, Mercury

17. Which is NOT a reason that the dominant surface feature on Mercury is impact craters.

- a. Smaller size
- b. Lack of geological activity
- c. Lack of an atmosphere
- d. Close proximity to the sun
- e. [All of the above ARE reasons]

18. The fact that Mercury and the Moon appear so similar suggests that which factor was the most important in the shaping of their surfaces?

- a. size
- b. distance from the sun
- c. temperature
- d. [All of the above]
- e. [None of the above]

19. Which is NOT a reason related to why it is so much colder on Mars than Earth?

- a. Mars is smaller size than Earth
- b. A current lack of geological activity of Mars.
- c. Mars' atmosphere is very thin.
- d. Mars is farther from the Sun than Earth
- e. [All of the above ARE reasons]

20. Which is the main reason that atmospheric conditions on Earth and Venus turned out so different?

- a. Venus is just a little larger size than Earth
- b. Venus is no longer geologically active
- c. Venus has a greenhouse effect
- d. Venus is closer to the sun than Earth
- e. [All of the above ARE reasons]

21. Which planet has the most evolved (changed) atmosphere since the time of its formation?

- a. Mercury
- b. Venus
- c. Earth
- d. Mars
- e. [All of the above have evolved about the same amount]

22. Which is NOT true about Jovian (outer solar system) moons?

- a. They can be as large as Earth's moon or even Mercury.
- b. They are unlikely to be geologically active or to retain an atmosphere due to their relatively small size,
- c. They are unlikely to be geologically active or to retain an atmosphere due to how far from the sun they are.
- d. Some have been discovered to be geologically active and with atmospheres, but both are unusual.
- e. [All of the above are true]

23. A comet's tail

- a. precedes its head through space.
- b. follows its head through space.
- c. is farther from the Sun than its head is.
- d. is closer to the Sun than its head is
- e. [None of the above]

24. Which part of a comet DOES NOT appreciably change in size as the comet approaches or recedes from the sun?

- a. nucleus
- b. coma (head)
- c. tail
- d. [neither b nor c change, only a does]
- e. [no part of a comet changes with proximity of the sun]

25. Which type of object can be a source for meteors?

- a. asteroids
- b. comets
- c. [Both A and B]
- d. [Neither A or B-meteors are their own unique class of object]
- e. [Actually, meteors and comets are different names for the same object, so the question does not make any sense]