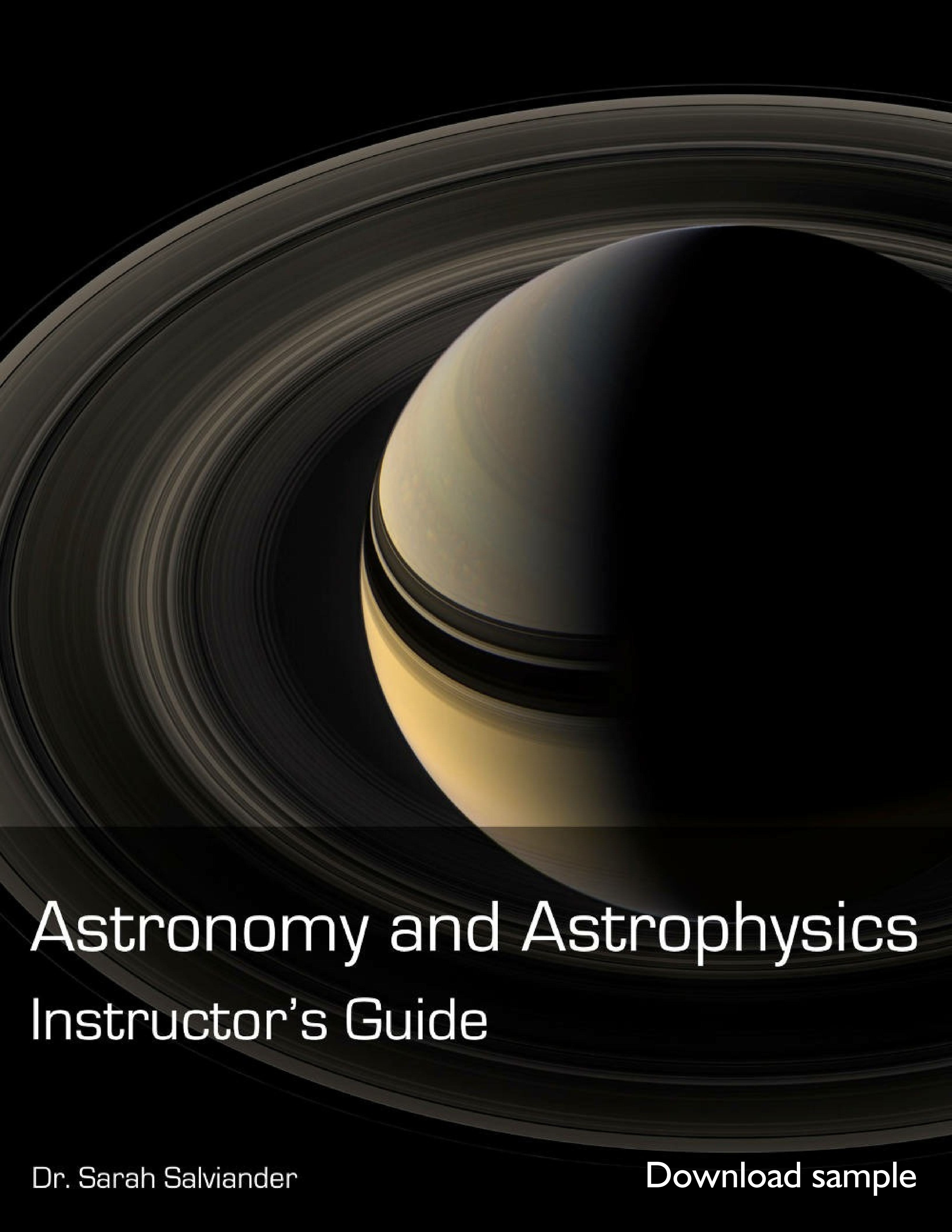

Astronomy and Astrophysics

Instructor's Guide

Dr. Sarah Salviander

CASTALIA HOUSE

ASTRONOMY AND ASTROPHYSICS: Instructor's Guide
by Dr. Sarah Salviander

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1. Homeschooling parents are permitted to use a single purchased copy of the Instructor's Guide, the Activity & Lab Book, and the Biblical Supplement for their family. A copy of the Exam Book must be purchased for each individual child.
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Contents

The cover photo shows Saturn and one of its moons, Titan, taken by the Cassini spacecraft. Credit: Cassini Imaging Team, SSI, JPL, ESA, and NASA.

1 Detailed Course Information

1.1 Course Overview

Astronomy is the study of the universe and its contents. It is a natural science—in fact, it is the oldest science, practiced in a limited way as far back as prehistoric times. Natural science is the study of the natural, or physical, world. Though this course is about astronomy and astrophysics, students will learn much that is applicable to all of the natural sciences, including some of the history of science, some of the tools of science, and how science works.

This course covers both "astronomy" and "astrophysics." In the modern world these terms are used interchangeably, but in the past they were distinct. "Astronomy" was used to describe activities like cataloging and studying the motions of celestial objects, such as comets, stars, nebulae, and galaxies, while "astrophysics" was used to describe the science of physics applied to these objects and the universe as a whole. In this course students will gain an appreciation for both simple observation of the motions of the night sky and the physics of the universe and its contents.

Students will learn about the night sky, the solar system, stars, the Milky Way, the many galaxies in the observable universe, the origins of our universe, classical and modern physics, and the latest in theoretical cosmology. This is a modern science course developed by a professional astrophysicist and is comprised of both well-established and cutting-edge material. There is no filler material or busywork. Students will receive only that which is necessary to understand astronomy and to go on to succeed in science at the university level. This is a science course, so there will be some mathematics involved. This will be kept at a level appropriate to the student's current grade.

1.2 Prerequisites

There is no science prerequisite for this course. The mathematics prerequisite is basic algebra, geometry, and trigonometry.

1.3 Note on Biblical Perspective

This course is presented from an agnostic perspective, without overt regard to any particular religious or philosophical tradition. However, it must be emphasized that nothing in this course contradicts the Bible. In fact, this material is highly supportive of biblical belief. This course includes an optional Biblical Supplement and corresponding lessons at the end of some of the chapters for those parents interested in incorporating a scriptural perspective into the course.

2 Course Organization

The course is organized into seven units encompassing a total of 18 chapters. The material for each unit is covered using a combination of the following:

1. Reading assignments about the topic
2. Review questions that reinforce the concepts
3. Activities involving an experiment, observation, or watching a video
4. Formulation of original questions about the material
5. Evaluation of the student's performance for each lesson
6. Unit exams that typically cover 2-3 chapters

2.1 Written Assignments

Review questions will be given for each chapter. Some questions will involve mathematical problems.

Answers to essay or short-answer problems should be written using complete sentences, beginning with a statement of the problem. For instance, if a question asks, "How does the Sun produce light?" the answer should be written, "The Sun produces light by converting some of its mass into energy."

Answers to mathematical problems should be completed in five steps: (1) Write out the equation(s) to be used; (2) perform any algebra necessary to obtain an expression in terms of the quantity being sought; (3) plug in the relevant numbers, including the appropriate units; (4) write down the answer, including the appropriate units; and (5) check the answer to make sure it makes sense. These steps are explained in more detail in the Mathematics Supplement.

2.2 Laboratory and Other Activities

In order for any idea to be considered scientific, it must be subject to experiment or observation. For this reason, students in this course will develop the skills necessary for conducting straight-forward experiments and observations through a variety of hands-on activities. Activities in astronomy courses are often referred to as laboratory exercises or "labs" for short. It may seem nonsensical to refer to astronomical observations as *laboratory* experiments, but it is actually quite sensible—in this case, the entire universe is your laboratory. **Note: Most universities require students to have taken science courses with lab components in order to gain admission. This course meets the lab component requirement, as long as *all* of the lab activities are performed, *including the optional labs.***

While a few items will need to be purchased especially for these activities, many of them can be completed with apparatus fashioned from household items (see the list of materials below). There are also a number of optional activities that involve the use of a telescope, if one is available or the family is willing to purchase one, but these are not required for the course.

Several other activities involve working in-depth with some of the more challenging concepts presented in the course or watching a video that reinforces the material covered in a lesson.

Family Involvement

If the family or homeschool co-op is comprised of a mix of older and younger children, parents are strongly encouraged to involve them all in mutual learning during the lab activities. The older children benefit from explaining concepts to the younger children (teaching is one of the best ways to learn), and the younger children benefit from the experience of the older children. This a major advantage of homeschooling that is generally unavailable in the highly-stratified public school setting. It should be utilized as much as possible.

2.3 Asking Good Questions

In this course there is an emphasis on students formulating their own questions about the material. This is important for two reasons. The first is that it requires the student to master the material, and the second is that the foundation of science is asking good questions. Good questions generally begin with "How," "Why" or "What if." The answer does not need to be known or even knowable in order to be a good question. Students will be required to come up with several original questions of their own for each chapter.

2.4 Exams

At the end of each unit, there is an exam that covers the material from the chapters of that unit. For each of Units 1-6, there are two exams; for Unit 7 there is only one. These are in the Exam Book. By having two exams for most units, the instructor has the option of offering a make-up should the student perform poorly on the first exam. The student can either replace the first grade with the second one, should s/he perform better the second time, or the instructor can average the grades for the two exams. If the student does well on the first exam, there is no need to use the second one.

2.5 Evaluation

Evaluation is not a precise process. To be accurate and useful, evaluation simply has to be done according to a plan that accurately reflects the content and intended outcomes of a course. This course comes with such a plan built into it. As the evaluator of your student, all you have to do is follow the guidelines listed below and use the evaluation forms provided. Don't worry too much about getting things exactly right, the evaluation you perform will work out well.

Evaluation Guidelines

These guidelines apply to **all** sections of the course: chapter review questions, activities, lab assignments, and unit exams.

1. Every question that has a single answer, whether it is in English or math, gets 1 point.
2. Every question that has a more complicated answer can be evaluated by counting the different/important parts of the answer in the answer key. This number will usually be between 2 and 5.

   The student's score on this question will be however many s/he included or got right out of the total number of parts possible.

   So, if a student is answering a question with four important parts in the answer key, and the student's answer includes three of those parts, the student's score on that problem is 3 out of 4.
3. For questions that ask for a table or graph to be constructed, you can assign a total value of 2 - 4 depending on how much work you think should go into the problem. Then assign a score based on how well you think the student did. For example:

0 - 2	0 for a problem not done at all or poorly done 1 for average work 2 for a problem done well
0 - 3	0 for a problem not done at all or poorly done 1 for a problem done but not acceptably 2 for a problem done well 3 for excellent work
0 - 4	0 for a problem not done at all 1 for a problem done but not acceptably 2 for a problem done at an average level 3 for good work 4 for excellent work

Calculating the score for an activity, lab assignment, review question section, or unit exam

Add up all the possible points for each part of the assignment. This will be the total points possible for the assignment. Then add up all of the points awarded to the student. The student's score will be a fraction with the total points awarded over the total points possible. For example, if there are 32 points possible for an assignment, and the student was awarded 25 points for his/her answers, the score for this assignment will be 25/32.

This fraction can be converted to a percent score by dividing the top number (total points awarded) by the bottom number (total points possible), and multiplying the result by 100:

$$25/32 = 0.78125 \quad 0.78125 \times 100 = 78.125 = 78\%$$

These numbers will be recorded in the evaluation forms, located at the end of the Exam Book, provided for the activities, labs, review questions, and exams. For example:

Evaluation Form for Chapter Activities

Here is a sample of what entries in an evaluation form would look like:

Activity Evaluation Form

Activity	**Points Awarded**	**Points Possible**	**Percent Score**
The Universe According to You, Part I	9	10	90
A Sense of Scale, Part I	10	12	83
A Sense of Scale, Part II	10	10	100
...	...	...	...
Total	29	32	91 %

Final Total Grade

All of the four parts of the course—activities, labs, review questions, and exams—are equally important. So, each part is given the same weight (25% of the course). The final grade will be calculated by adding up the final percent score for each of the four parts of the course and dividing by four.

Here is a sample of what a final score for the course would look like:

Final Score for the Course

Component	**Total % Score**		**25% of Total Score**
Review Questions	88	×0.25	22.00 %
Activities	91	×0.25	22.75 %
Labs	84	×0.25	21.00 %
Exams	93	×0.25	23.25 %
Total	–	–	89 %

The final grade is calculated by adding the 25% of Total Score for each component:

$$22.00 + 22.75 + 21.00 + 23.25 = 89$$

Guidance for Evaluating the Labs

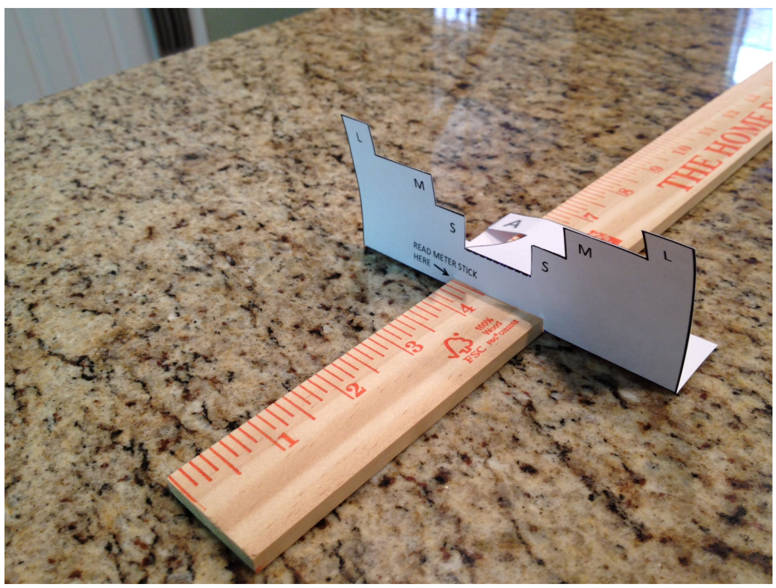
Here are the items to consider when judging the quality of each lab. (Not all items apply to each lab.)

- Is the lab complete or are there missing sections?
- Are data tables filled out?
- Are math problems done correctly?
- Are graphs drawn and labeled correctly?
- Are any anomalies in measurements addressed?
- Are observations complete and descriptive? Drawings complete and detailed?
- Are questions answered correctly?

Below is an example of how to assess a lab using the first lab of the course, Angles and Distance.

Angles and Distance

Did your student construct the cross-staff properly, as shown in the photos? If not, this could seriously affect your student's results. Keep this in mind as you assess the lab.

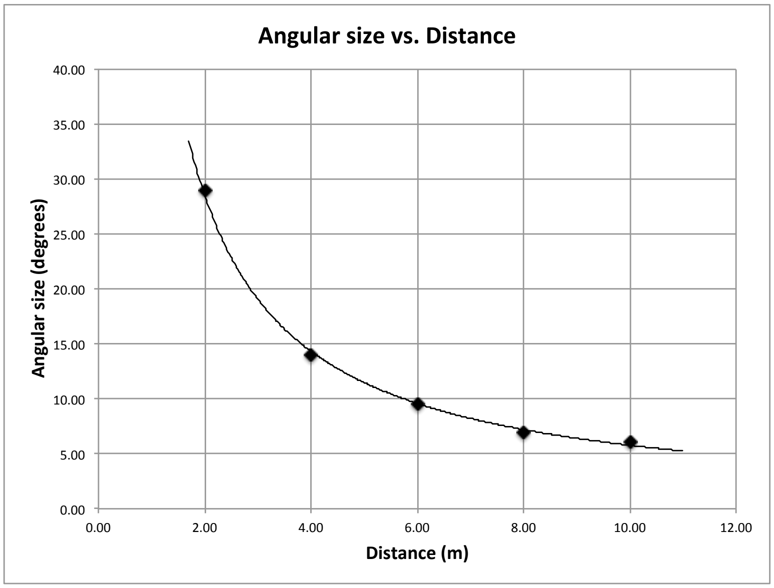


Did your student draw the graph and label it correctly, as shown in Figure 1? A properly drawn and labeled graph will have: title, x-axis label and scale with units, y-axis label and scale with units, data points, and a curve drawn through the points. The actual measurements made by your student will likely differ from those shown below; just make sure your student's graph looks qualitatively similar.

Skipping the graph or getting it seriously wrong should be heavily penalized, since it is central to the lab. Failure to include title, labels, or a line through the points should be penalized more modestly.

Did your student attempt all of the questions? Did your student answer them correctly? Skipping questions should be penalized more heavily than giving incorrect answers. Minor errors should only be modestly penalized.

Did your student complete the data sheet? Skipping the data sheet or getting it seriously wrong should be heavily penalized, since it is central to the lab. Skipping some of the entries with no explanation should be moderately



penalized, depending on how many data are missing; failure to address any anomalous data should drop the grade down, but less significantly; minor errors should be penalized modestly.

Data Sheet

Type of object used for the experiment: cardboard box

Measured size of your object: 0.50 m

Table 2

Distance r (m)	Cross-staff reading (cm)	Sights used (S, M, or L)	Angular size θ (degrees)	Physical size s (m)
1.5	15.0	L	19.7	0.52
3.0	30.5	M	9.5	0.50
4.5	22.5	S	6.3	0.49
6.0	30.0	S	4.9	0.51
7.0	34.5	S	4.3	0.53

Average physical size: 0.51 m

% error: 4.0 %

Did your student calculate the average and % error correctly? Serious errors or omission should be penalized more heavily than minor errors.

The penalties suggested are not hard and fast rules. You may find, after grading each section of the lab, that all of the penalties add up to a serious grade drop in spite of the fact that the overall attempt by your student wasn't that bad. In such cases, use your own sense of how well your student did and assign an overall letter grade that reflects the effort. Was it an overall solid "B" effort in spite of the fact that your student got a couple of questions wrong? Was it an overall "C" effort even though your student forgot all of the labels on the graph and got two questions wrong? Go ahead and give the lab an 80% or a 75%, respectively.

3 Course Materials

3.1 Required Materials

A comprehensive list of materials for the activities is listed in Section 3.3. Briefly, this course requires:

- the use of a computer connected to the Internet and a printer.
- a scientific calculator, that is, a calculator with functions such as $\sqrt{}$, x^2, y^x, EE, log, sin, cos, etc. Basic scientific calculators can be purchased for about $20 at stores like Wal-Mart and Best Buy.
- a Miller Planisphere or similar "star wheel" (see Section 3.3 for details)
- a stopwatch. Digital watches are fine. Most smart phones have stopwatch apps; alternatively, an inexpensive stopwatch can be purchased at local retailers.
- a linear diffraction grating or diffraction glasses (see Section 3.3 for details)
- household items such as pencils, rulers, scissors, tape measures, string, etc.

3.2 Optional Materials

These items will enhance the student's experience in the course, but they are not required:

- a telescope (see the next section for details)
- a tripod and other accessories for the telescope

3.3 Materials for Activities

Planisphere

A planisphere, also known as a star wheel, is a celestial roadmap. It shows which stars are in the sky and where, depending on the date and the time. The preferred planisphere for this course is either the Miller planisphere or The Night Sky planisphere. These are available at your local planetarium gift shop or at online retailers such as Amazon.com for a reasonable price. Care must be taken to select the planisphere appropriate for where you live, as the view of the sky depends on your latitude.

Diffraction Grating

A diffraction grating is a small piece of etched plastic that is used for spectroscopy, the study of the components of light. There are two types of diffraction grating acceptable for this course. One is a linear diffraction grating mounted on a slide, which is easy to hold and spreads the light out in just one direction. We recommend the linear diffraction grating slide (1000 lines/mm) by Rainbow Symphony, usually available for around $10 or less on Amazon.com. The other is a pair of diffraction glasses, which are popular for viewing fireworks or Christmas lights. We recommend the diffraction glasses by Fireworks or Rainbow Symphony, which, as of the publishing of this curriculum, are available singly for around $2 or less or in sets of several pairs for $2 - $10.

Telescope (Optional)

The foundation of astronomy is observation, and for that reason it is recommended that students have access to a telescope for the optional activities. If your student is planning to apply for admission to universities, s/he must have credits for science courses with lab components—performing the optional telescope activities along with all of the other activities will satisfy this requirement for one course. Even a small, inexpensive telescope will enhance your student's experience, and when the course is over, you can use your telescope for family star parties for years to come. If you already own a telescope or can borrow one, that is wonderful. If not, you can purchase an inexpensive beginner's telescope. We like the Orion SpaceProbe 3 Reflector, which comes with a tripod. Telescopes like this are often available for around $100 or less at online retailers such as Telescopes.com, Amazon.com, or individual telescope retailers such as Orion Telescopes (telescope.com). Before selecting a telescope for purchase, read through all of the customer reviews. Telescopes with high ratings by customers—for example, 4/5 stars or higher—are typically of good quality and easy to use. Avoid telescopes that have several low ratings by customers.

There are a few basic considerations when selecting a telescope. Do you want something small and portable? Something large and powerful? Are you constrained by a budget? What kinds of objects are you mostly interested in observing once the course is over? *Sky & Telescope* magazine has some helpful articles online to assist the beginning astronomer choose an ideal first telescope based on these considerations and more:

`http://www.skyandtelescope.com/equipment/basics`

If you don't already have a tripod, or the telescope you intend to purchase doesn't come with one, you may want to purchase one suited for your telescope. A tripod is handy, but not required for tabletop telescopes, such as the Orion FunScope, or larger Dobsonian telescopes, as long as you can provide some sort of stable surface for it. We also strongly recommend that you purchase a moon filter for the telescope. A moon filter significantly reduces the glare of the Moon through the telescope, making it easier to see features on the surface. If you decide to purchase one, make sure its diameter is the same as that of your eyepieces. For instance, the Orion SpaceProbe's eyepieces have a 1.25" diameter, so this is the diameter you would need for a moon filter.

Full list of materials needed for activities

The following is a full list of the materials required for the activities in this course:

- audio recording device (optional)
- balls of differing weight
- binoculars (optional)
- blanket and pillow or lawn chair
- calculator
- cardboard box or other large movable object
- cardboard, small piece or small box
- computer and printer
- diffraction grating or diffraction glasses
- electric buzzer (75 dB Piezo Electric Buzzer from RadioShack or similar) + batteries
- flashlight
- fluorescent light
- foam ball or tennis ball (that you can cut open)
- heavy cardboard
- household string
- incandescent light bulb, regular
- incandescent light bulb, red "party bulb"
- marker, fine-tipped
- moon filter for telescope (optional)
- paper, card stock
- paper, printer
- paperclip, large
- pens or pencils, colored

- pencil and eraser
- planisphere
- plastic drinking straw
- protractor
- pushpins
- red marker or red cellophane
- rubber band
- ruler
- scissors
- scotch tape
- stopwatch
- tape measure
- telescope (optional)
- tripod for telescope (optional)
- yard stick or meter stick

4 Book Lists

4.1 Core Book and Videos

***Astronomy Notes* by Nick Strobel**
A free online textbook available on the SixDay Science website:
`http://www.sixdayscience.com/curriculum/textbook/`

The original textbook is available on Nick Strobel's website:
`http://www.astronomynotes.com`

We recommend students use the SixDay version, as it has been customized for use with this course.

Please note that Professor Strobel has graciously made his excellent textbook available online for free and grants permission for others to copy it. We encourage you to support his efforts by making a donation:
`http://www.astronomynotes.com/support.htm`

***The Elegant Universe* and *The Fabric of the Cosmos* (NOVA)**
Television programs based on books by physicist Brian Greene. They aired on PBS and are now viewable for free on the PBS/NOVA website:
`http://www.pbs.org/wgbh/nova/physics/elegant-universe.html`
`http://www.pbs.org/wgbh/nova/physics/fabric-of-cosmos.html`

Miscellaneous videos and interactives
Various other online videos and interactive programs are required for some of the lessons. All but one are available for free online viewing, mostly on the PBS/NOVA website. The only video that may require a purchase or rental is the movie *Contact* directed by Roger Zemeckis.

4.2 Optional Publications

The resources on the core list are sufficient for students to complete the course. The following extended list of books and magazines is provided as a resource for students who wish to know more about some of the more popular topics in the course. All publications on this list are written at a popular, non-technical level.

Current Topics in Astronomy:
Sky & Telescope magazine

One of the most respected science periodicals in the U.S., covering a broad range of topics in amateur astronomy as well as current topics in the science of astronomy and astrophysics.

History of Science / Astronomy / Physics:
From Clockwork to Crapshoot: A History of Physics by Roger G. Newton

Covers the history of physics and astronomy from Greek antiquity through the Renaissance and to the present day. An excellent primer on the history of science in general, since science began with astronomy and physics.

General Physics:
Six Easy Pieces: Essentials of Physics Explained by Its Most Brilliant Teacher by Richard P. Feynman

Feynman, a Nobel laureate in physics, was arguably the most famous scientist of the 20th century. The lecture notes for his legendary freshman physics course at the California Institute of Technology were compiled into three volumes that came to be known as *The Feynman Lectures on Physics.* This book presents six basic ideas from his lectures in brief essays.

The Big Bang / Cosmology:
Big Bang: The Origin of the Universe by Simon Singh

A history of modern cosmology that follows the famous architects of the big bang theory and the heated scientific debate that raged over whether the universe was eternal or had a beginning.

Quantum Physics:
Alice in Quantum Land: An Allegory of Quantum Physics by Robert Gilmore

Gilmore adapts Lewis Carroll's famous *Alice in Wonderland* story to explain the often puzzling concepts of quantum physics. The book follows a narrative style and includes charming illustrations of some of the concepts.

Black Holes / Relativity:
Black Holes and Time Warps: Einstein's Outrageous Legacy by Kip S. Thorne

An excellent and entertaining primer on Einstein's Theory of Relativity and its "outrageous" implications, including black holes, wormholes, and time warps, woven together with a thought-provoking history of 20th century physics.

Dark Matter / Dark Energy:
Dark Side of the Universe: Dark Matter, Dark Energy, and the Fate of the Cosmos by Iain Nicolson

Nicolson explains the concepts of dark matter and dark energy—the mysterious substances that make up 98% of the "stuff" of the universe—in the context of the origin and overall development of the universe. Includes attractive full-color illustrations and photographs.

Anthropic Principle:
The Goldilocks Enigma: Why Is the Universe Just Right for Life? by Paul Davies

Davies discusses the precision tuning of our Universe, why the conditions seem to be exactly right for the emergence of life on Earth, and the implications of this astonishing discovery.

String Theory / Multiverse:
The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory by Brian Greene

Greene presents the latest in cutting-edge theoretical physics, a field called string theory, which is a mathematical attempt to resolve the biggest challenge confronting modern physics—reconciling the successful theory of the very large (Einstein's general relativity) with the equally successful theory of the very small (quantum mechanics). Also includes a discussion of the most contentious idea in modern cosmology—the multiverse.

Geometry / Dimensionality:
Flatland: A Romance of Many Dimensions by Edwin A. Abbott (available for free at Project Gutenberg)

A timeless fantasy classic that envisions the travels of a geometrical inhabitant of the two-dimensional Flatland to realms of different dimensions. An excellent pre-Einstein primer on geometry and dimensionality.

Note for Christian parents: An optional book list covering topics of science and how they relate to the Bible, metaphysics, and religion, is provided in the Biblical Supplement.

5 Syllabus

Below is the 36-week schedule for the 18 chapters in the course. Chapters with the number of lessons in parentheses include optional telescope activities. A double-asterisk (∗∗) after a topic indicates that a unit exam takes place at the end of that chapter.

5.1 Units and Chapters

Chapter	Lessons	Book	Topic
Unit 1			
1	11	AN	Astronomy as a Science and a Sense of Scale
2	7	AN	Method for Finding Scientific Truth
3	15	AN	Astronomy Without a Telescope ∗∗
Unit 2			
4	7	AN	History of Astronomy
5	12	AN	Newton's Law of Gravity
6	7	AN	Einstein's Relativity ∗∗
Unit 3			
7	10	AN	Electromagnetic Radiation (Light)
8	7 (8)	AN	Telescopes ∗∗
Unit 4			
9	11 (15)	AN	Planetary Science
10	8	AN	Solar System Fluff ∗∗
Unit 5			
11	10 (12)	AN	Determining Star Properties
12	6	AN	The Sun and Stellar Structure
13	10	AN	Lives and Deaths of Stars ∗∗
Unit 6			
14	6 (8)	AN	The Interstellar Medium and the Milky Way
15	10	AN	Other Galaxies and Active Galaxies
16	13	AN	Cosmology ∗∗
Unit 7			
17	7	AN	Life Beyond the Earth
18	14	EU & FC	String Theory and the Multiverse ∗∗

Core resources	
AN	*Astronomy Notes* textbook
EU	*The Elegant Universe* (NOVA program)
FC	*The Fabric of the Cosmos* (NOVA program)