We hope that you recognize that implementing every one of this book's recommendations is an impossible goal. Rather, it is our vision that you can select a big idea or two each semester and adapt them to work in your specific teaching environment. You certainly do not need to include collaborative group learning tasks, ConcepTests, and portfolios into every class meeting—nor should you. What is most important is that you take the time needed to adequately reflect on what is working in your classroom and what needs improvement in order to move your ASTRO 101 course to a more learner-centered environment. Given this, let us begin!

Questions to Think about BEFORE You Read This Book

- **What is my greatest strength as a teacher?**
- **How do I want my students to be different as a result of taking my ASTRO 101?**
- **If I walked into the library and saw a group of my students studying astronomy, what exactly would I like to see them doing?**
- **What would I most like to change about my ASTRO 101 course?**

Chapter 2
Goals and Objectives

What is the single most important thing you can do to improve your ASTRO 101 course? Take the time to write down the goals for your course. A well-known adage from trainers in physical fitness and advisors in financial planning is that "a goal isn't a goal unless you actually write it down—otherwise, it's just a wish." This idea applies equally well to teaching ASTRO 101 because if you don't know where you want your students to get to, how will you know if they made it?

The goals faculty set for ASTRO 101 vary widely. Perhaps you want to have the most popular class on campus with the highest enrollments or perhaps you want to be known for attracting the most students from the business college to become astronomy majors. Maybe, even, you want to have the reputation for giving the hardest tests of any general education course.

When thinking about your course goals, it is often helpful to consider how you want your students to be different as a result of taking your class.

Whatever you choose as your overarching course goals, we do suggest that you center your goals on students rather than on yourself. In other words, it is often helpful to consider how you want your students to be different as a result of taking your class. Do you want them to be able to point out constellations to their friends and family or do you want them to be able to explain the inferential evidence that suggests dark matter abounds in the universe? Or, maybe both are appropriate.

When we survey astronomy faculty about what goals are most important to them, we find that they fall into three broad categories (viz. Adams, Brissenden, Duncan, & Slater, 2001). The first is that students understand the big ideas in astronomy. These big ideas most often include the electromagnetic spectrum as a tool, size and scale of the cosmos, spectroscopy, and cosmology. The second common category is that students understand something about how science is done. This involves understanding and appreciating the nature of science, the scientific method as applied to astronomy, the influence of technology, weaknesses of pseudosciences, and careers in astronomy. A third goals category relates to engendering positive student attitudes about astronomy—and science in general. Many faculty describe encouraging students to become life-long learners in astronomy, choosing to read news and magazine articles on astronomy, visiting museums and planetaria, and maintaining a desire to look through telescopes such as at a local astronomy club. Let us emphasize again that these overarching faculty course goals are about students and, although measuring the degree to which they are achieved might be difficult (more on this later), they do provide guidance for curricular decisions. No matter what your goals are—and we think you could do a lot worse than adopting some version of the ones just listed—it is always worth sharing them with your students and asking yourself exactly how each element of the course contributes to those goals.

WHO ARE YOUR STUDENTS?

Let's take a step back from goals for a moment because how you structure your course goals depends quite a bit on who your students are. In other words, your goals might look quite different depending on whether your course is filled with science majors at M.I.T. or filled with nonscience students at the University of Arizona.

So, who are your students? As part of a national survey of astronomy knowledge, Grace Deming and Beth Hufnagel (2001) collected student demographic information. In their wide-ranging survey, they found that ASTRO 101 student demographics closely mimic the general population of undergraduates across the country. The slight majority of ASTRO 101 students are women (52%), more than 65% of students are under 20 years of age, and 92% report that ASTRO 101 is their first college astronomy course. The distribution of ASTRO 101 student majors also reflects national norms, where 85% of undergraduates having declared majors outside of science, engineering, or architecture. Thirty-five percent of students are majoring in the humanities, social sciences, and the arts. Few students have confidence in their abilities in mathematics and science. In fact, whereas only 41% of ASTRO 101 students rate themselves as "good" or "very good" at mathematics, even fewer (34%) view themselves as such in science. In short, what these students are interested in and how they view themselves performing in science courses is far from optimal—indeed, these students present an arduous but worthy challenge to the ASTRO 101 teacher!

We would be somewhat surprised if the students at your institution were far different than this. However, we encourage you, at a minimum, to talk to colleagues who have taught the course before, talk to department administrative assistants who handle student paperwork, and survey your course enrollment lists to look at the distribution of declared student majors. You will find that understanding who your students are and where they are coming from will bring you much closer to meeting your course goals because you can help them make connections between their academic majors and the realm of astronomy. A few examples of making the course relevant to nonscience majors are worth noting. With some effort one can relate the interests of photography and film majors to astronomy through art and science fiction (an archive of digitized space move clips is available online at URL: http://graffiti.cribx1.u-bordeaux.fr/roussel/anim-enf.html). Similarly, recent news reports about the space telescope or discoveries from an interplanetary probe can be highlighted for journalism majors. Even business and accounting majors can be enticed by taking a moment to point out how stock prices for major contractors such as TRW and Lockheed Martin change when scientific or technological advances are made.

The one thing that we are reasonably confident in asserting is that few of your students are future physics and astronomy majors. This is important because you need to appreciate just how different you are (or ever were!) from most of your students. Their interests and talents are different from yours and most of them don't learn science the way you were able to. Although we firmly believe in the power of reflection as a means of directing change, it can actually be counterproductive to think back to when you were a student and try to emulate the teaching style and seemingly lucid explanations of those professors who most affected you. Just because it worked for you doesn't mean it will work for your students and, even worse, it may mean that it won't work for your students at all! To teach your students, you need to find out what works for them.

WHAT ARE YOUR STUDENTS EXPECTING TO LEARN?

Probably the most common reason that faculty receive low course evaluations from students is an enormous mismatch in what faculty and students expect ASTRO 101 to be about.

Box 2.1 Student Expectations

The Most Frequent Things Students Expect to Learn in ASTRO 101

- constellations
- stars
- planets
- galaxies
- black holes
- comets
- Moon
- Sun
- weather
- atmosphere
- UFOs & the unexplained

NOTE: Midcourse surveys reveal that students thought they would learn more constellations and that they are surprised that the other topics were covered in such depth.
Adapted from Lacey and Slater (1999)

We strongly urge you to conduct a brief written survey of your students asking them what they would most like to learn in ASTRO 101. In truth, you don't have to change any of your course plans fundamentally; however, you can point out when you get to certain topics that this is what they stated was a high priority. A truism exists among many college faculty that so-called great teachers are really just marketing and sales experts. If there is indeed any truth to this, the lesson is that you will benefit greatly from figuring out how to create a win-win situation for you and your students by matching students' perceptions with the structure of your course. Even in cases where you will not be addressing a particular topic of interest to your students, it helps to know this in advance so that you can acknowledge it to your class and explain why you have made this choice.

As a last suggestion, if your course fulfills a general science requirement as part of the overall college or university goals, other faculty have found it surprisingly useful to look at the overarching college or university goals for general education classes. Be sure that your goals are aligned with those written elsewhere. You might even find just the exact language you need to focus your own course goals.

COMPOSING LEARNING OBJECTIVES

Once you have written down your three, four, or five overarching course goals, the next step is to decide the specific learning objectives for your students—generally related much more to content—that will contribute toward their reaching the course goals. The writing of learning objectives should not be a tedious or time-consuming task and yet it is one that can prove enormously valuable. Learning objectives should be written as a guide for you and your students about what *specific* aspects of the course are important. And when we say specific, we mean specific. *Understand Kepler's laws* is far too general. *State Kepler's first law, use Kepler's second law to reason about the position and motion of orbiting bodies,* and *apply Kepler's third law to the motions of asteroids* are learning objectives that clearly tell the student what they should be studying and at what level of proficiency they need to reach.

Writing learning objectives that simultaneously guide how you present material, help students monitor their own learning, and inform your testing strategies is somewhat of an art form that improves with practice (and, dare we say, perhaps some friendly peer review). One way that faculty specify the levels of complexity and depth students need to achieve is to employ *Bloom's Taxonomy of Educational Goals and Objectives.* Bloom (1956) defined "understanding" at six hierarchical levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. The first three levels, sometimes called the lower order thinking levels, emphasize recall, literal translation, and application of concepts to well defined situations. The second three levels, often referred to as the higher order thinking levels, focus on breaking apart complex ideas for use in novel situations, and integrating ideas across numerous concepts. Although most of us would agree that ASTRO 101 should focus on the higher-order levels, you will likely find that writing learning objectives at the lower-order levels is many times easier than writing objectives at the higher-order levels. More important, you will also find that it is infinitely easier to create test items that probe the lower-order levels than the higher-order levels. As many of our nonscience majors enter our courses with almost no basic knowledge of astronomy and very naïve views of science, it is essential that students gain some lower-order knowledge—and that you assess this knowledge. However, this does not mean that your course should be limited to lower-order knowing only; selecting specific topics in which to expect students to gain higher-order understanding enriches your course and, many would argue, is what makes it an engaging college experience.

Box 2.2 Bloom's Taxonomy of Educational Objectives for Knowledge-Based Goals for "Understanding the Seasons"

Level of Expertise	Description of Level	Example of Measurable Student Outcome
Knowledge	Recall or recognition of terms, ideas, procedure, theories, etc.	Student states when the first day of spring is.
Comprehension	Translate, interpret, extrapolate, but not see full implications or transfer to other situations, closer to literal translation.	Student describes what the summer solstice means.
Application	Apply abstractions, general principles, or methods to specific concrete situations.	Student explains why seasons are reversed in the southern hemisphere

Analysis	Separation of a complex idea into its constituent parts and an understanding of organization and relationship between the parts. Includes realizing the distinction between hypothesis and fact as well as between relevant and extraneous variables.	Student can analyze what Earth's seasons would be like if Earth's orbit were perfectly circular.
Synthesis	Creative, mental construction of ideas and concepts from multiple sources to form complex ideas into a new, integrated, and meaningful pattern subject to given constraints.	Given a description of a planet's seasons, student can propose plausible orbital and tilt characteristics.
Evaluation	To make judgment of ideas or methods using external evidence or self-selected criteria substantiated by observations or informed rationalizations.	Student can distinguish what would be the important, and irrelevant, variables for predicting seasons on a newly discovered planet.

Adapted from Brissenden, Slater, and Matheiu (2002).

We have included one of our lists of ASTRO 101 learning objectives in Appendix F. If someone were to adopt these learning objectives uncritically for his or her course, then we would have failed in our message. Your learning goals should guide your course sequence and inform your students about what is important. Similarly, well-articulated course goals and objectives will guide you when writing exams. As a matter of apology, we should mention that our style of writing learning objectives does not correlate highly with the common wisdom for composing each learning objective such that it is measurable (e.g., The student will identify the end states of stars with masses $0.5M_\odot$, $1M_\odot$, $8M_\odot$, and $20M_\odot$). Moreover, when we have shared our list of course objectives with colleagues, we've had responses ranging from a shocked, "you *only* cover 24 concepts in your course" to an equally shocked, "how could you *possibly* cover 24 concepts in your course." Along these same lines, we've had students attempt to memorize the course objectives verbatim, not realizing that the words themselves are not the content of our course. Despite these issues, we provide these to give you a feel for what a list of learning objectives might look like.

HOW MUCH MATH ARE YOU GOING TO INCLUDE?

One of the outstanding questions—and it is directly related to how you write your goals and objectives for ASTRO 101—is what sort of mathematics to include in your course. We described earlier that the vast majority of students who take ASTRO 101 have limited backgrounds and woefully low confidence levels in mathematics. It probably comes as little surprise that the appropriate mathematical level at which to teach introductory astronomy is a topic hotly debated among astronomers.[1] At the risk of over simplifying the positions, one side suggests that teaching astronomy without mathematics is merely pandering to students and that asking them to complete calculations will enhance their mathematical abilities and appreciation of the science. The perspective is that astronomy is a quantitative science expressed most elegantly in the language of mathematics, and students should be exposed to this beauty. The contra view holds that college students have already had more than a decade of mathematics instruction and that a heavy emphasis on mathematics in the astronomy survey course will only serve to convert them from students who think they "cannot do math" into students who are completely convinced of that fact. This perspective holds that college courses for nonscience majors should avoid off-putting mathematical rigor in favor of a descriptive approach that is also designed to improve students' attitudes toward astronomy, and science in general. Of course, most astronomy instructors recognize that there is some validity to both perspectives and therefore attempt to strike a tricky balance between a course with too much math, which confuses and scares off the students, and one with too little math, which fails to reflect the true nature of the discipline and may well sell many of the students short.

We would like to suggest an alternative perspective—one that first distinguishes between *mathematics* and *arithmetic*. When astronomers ask if we use "math" in ASTRO 101, we are never really sure how to answer. To set up a dichotomy, let us first define *arithmetic* as the process of performing an algorithm to generate a numerical result, a process our students call "plug and chug." A standard example is requiring students to

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[1] Much of the material in this section has been adapted from the article "Mathematical Reasoning Over Arithmetic in Introductory Astronomy," The Physics Teacher, **40**(5), 268, 2002, T. F. Slater and J. P. Adams. Reprinted with

calculate the length of the semimajor axis for an asteroid given its orbital period. Other examples include asking students to compute the force of gravitational attraction between Pluto and Charon, the apparent magnitude of a star at a given distance and absolute magnitude, the wavelength of a photon with a particular frequency, and a star's luminosity given its temperature and radius.

Although mathematically sophisticated students can "play" with the required formulae and actually seek meaning in the algebraic symbols, this is most likely not the case for the numerous math-phobic students we frequently find in our courses for nonmajors. With their calculators in hand, and a fair degree of coaching, students can indeed learn to perform the operations needed to get an acceptable numerical result. However, we submit that successfully performing algorithms does little to enhance students' understanding of the underlying concepts; we do not include such calculations in our courses.

In contrast to this computational-calculator view, if we define *mathematics* as the study of patterns and a language used to communicate ideas, then we definitely include considerable mathematics in our introductory astronomy course. One of our goals is for students to be able to articulate relationships between variables to reason about the relationships between physical variables. We have found that, with some effort, we can ask students to do this without relying on calculators or formulas. For example, rather than giving students the formula for the Stefan-Boltzmann law for relating luminosity to temperature and surface area, we ask students to reason about the relative diameters of stars at the same temperature when given their comparative luminosities. Other examples of the kinds of questions we focus on, as well as the kind of reasoning we would expect, are listed in Box 2.3.

It is difficult to underestimate how intensely the majority of ASTRO 101 students lack confidence with concepts in mathematics. To demonstrate one way we introduce students to mathematical reasoning without arithmetic is to pose the following question: "What would a graph of astronomers' weights versus heights look like compared to a graph of astronomers' IQs versus heights?" We ask them to label the appropriate axes on the graphs shown in Box 2.4. When first presented with such a task, it is common for students to throw up their hands in despair but, working in collaborative teams, most are able to reach an understanding on the nature of correlated versus uncorrelated data—an understanding that it is all too easy to assume students will already have.

Box 2.3 Example Questions Emphasizing Mathematical Reasoning

Question Prompts	Expected Reasoning
Sirius has an apparent magnitude of about –1.5 and an absolute magnitude of about +1.4. Would you have to wait more or less than 30 years for a radio signal to arrive from Sirius?	*ANS: As absolute magnitude is defined as the apparent magnitude at 32.6 ly (light-years) and because the apparent magnitude is brighter than the absolute magnitude, the star must be closer than 32.6 ly so the radio signal would likely take less than 30 years.*
You observe two stars with the same absolute magnitude and determine that one is a type B star while the other is a type G star. What can you conclude about the sizes of the stars?	*ANS: The type G star has a lower surface temperature than the type G star. The only way it can emit the same amount of light energy it to be larger than the type B star.*
You use the method of spectroscopic parallax to determine the distance to an F2 star as 43 parsecs. You later discover that the star has been misclassified and is actually a type G7. Is the actual distance to the star greater than or less than 43 parsecs?	*ANS: Because the star is on the main sequence, a lower temperature also means a lower luminosity. When the star was thought to be more luminous, its distance had to be 43 parsecs to explain its brightness as observed from Earth. As it is actually less luminous than was thought, it must be located closer to explain its appearance.*
Hadar, at a distance of 90 parsecs, has absolute magnitude is –4.1. Which of the following is most likely Hadar's apparent magnitude? a. –8.8 b. –3.9 c. 0.6 d. 85.9	*ANS: If it were 10 parsecs away, it would appear magnitude –4.1. It is nine times farther away than that, which means we should receive 81 times less light. 100 times less light would be a 5-magnitude difference so Hadar's apparent magnitude should be a little less than 5 magnitudes greater. (c) is most reasonable.*
Canopus has apparent magnitude –0.7 and absolute magnitude –3.1. Is Canopus located more or less than 10 parsecs away?	*ANS: Canopus would appear brighter at a distance of 10 parsecs than it appears at its true distance. It must be located more than 10 parsecs away.*
Ross 128 has a parallax angle of 0.30 arcseconds as measured from Earth. If an observer on Mars could repeat the measurement, would the parallax angle be greater or less than 0.30 parsecs?	*ANS: As the observer would be moving a greater distance between observations, the star would appear to move more compared to the background stars. Its parallax angle measured from Mars would be greater than 0.30 parsecs.*
You observe two Cepheid variable stars, A and B, which appear the same average brightness. Star A has a bright-dim-bright period of 5 days, while Star B has a bright-dim-bright period of 18 days. Which star is located closer to Earth?	*ANS: From the period-luminosity relationship for Cepheid variables, we know that star B is more luminous than star A. As star B appears the same brightness, it must be located farther away.*

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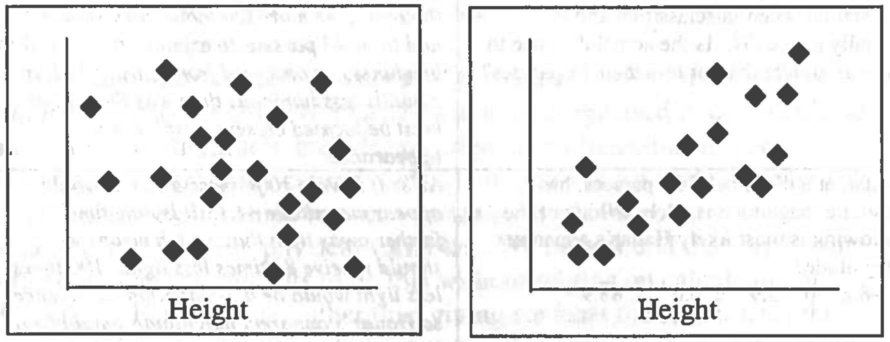
It is our contention that not only can conceptual questions require mathematical reasoning but that this reasoning is often more sophisticated than what is required to produce answers for more traditional quantitative problems requiring the use of formulas. Helping students think in terms of mathematical patterns and relationships is not easy, but it seems to be many times more rewarding that meaningless calculations. Similarly, questions specifically focusing on reasoning do in fact mirror the discipline of astronomy much more appropriately than do simple computations.

Box 2.4 Mathematical Reasoning without Arithmetic

"One of the following is a graph of astronomers' weights versus heights while the other is a graph of astronomers' IQs versus heights. Identify the graphs, label the axes, and explain your reasoning."



Using a philosophy of *mathematics over arithmetic* has important consequences for writing your ASTRO 101 learning objectives. For example, a recurring coffee-room debate is whether students should learn luminosities and flux or absolute and apparent magnitudes. When employing *mathematics over arithmetic* perspective, there is no debate. Asking students to calculate the luminosity of a 3500K star with a diameter of 10^7 km is an exercise in arithmetic. However, asking students to estimate the distance to a star that has an apparent magnitude of 4 and an absolute magnitude of 5 is perfectly appropriate (*the answer we are looking for is "a little less than 10 pc"*). Other places in our course that we infuse mathematics include historical measurements about the relative distances to Sun and Moon, classifying morphological characteristics in galaxies and spectra, and comparing intensity versus wavelength curves for various objects—all without a single formula. In short, if the students can successfully and powerfully use the concept, then we include it.

INCLUSIVE ASTRONOMY TEACHING

We would be negligent if we avoided mentioning that there is a longstanding tradition of teaching astronomy from a Eurocentric perspective. In and of itself, adopting a European emphasis to ASTRO 101 is not a bad thing. However, teaching from this perspective sometimes makes it difficult for the diverse student body in ASTRO 101 to see connections between astronomy and their personal heritage. As a discipline, astronomy has grown and benefited from a wide range of approaches, and our courses need to reflect this in some way.

Box 2.5 Inclusive Astronomy Teaching

Some Questions to Ask Yourself about Being Inclusive
- Do I use *he* and *she* equally in my examples?
- Do I use ethnically diverse names for people in my examples?
- Do I call on men and women equally in class?
- Do I mostly describe the work of male astronomers?
- Do I show students that science is a creative endeavor by many people?
- Do I describe telescopes operated by countries other than the United States?
- Do I point out the historical developments from cultures other than European-American?
- Do I provide multiple ways for students to obtain the concepts in addition to attending lecture?
- Have I made specific arrangements for physically disabled students to look through telescopes?

From a perspective of teaching that focuses on students, inclusive teaching that recognizes a diverse student body is paramount. Most faculty are aware that they should vary equally between the pronouns *he* and *she* and that a wide range of ethnic names should be used in examples. They are also aware and that the historical contributions of underrepresented groups and non-Western cultures should be included in courses (e.g, female astronomers' contributions to spectral classification, Mayan time keeping, Polynesian voyaging). However, work by Bianchini and her colleagues (2002) suggests that the primary reason that faculty do not emphasize diverse perspectives on science is that faculty are not able to find time to educate themselves on these issues, and aggregate work desperately needs to be done in this regard for interested faculty.

Moreover, the road to providing a truly inclusive ASTRO 101 class is a much longer one than most of us acknowledge. Authors, such as

Bianchini et al. (2002), Rosser (1997), and Banks (1999), suggest that merely adding side notes about the work of underrepresented people has merit, but is insufficient. They argue that teaching inclusively should focus on enabling students to consider concepts from diverse perspectives and to appreciate that knowledge is socially constructed. As much as we would like to, we are not in a position to provide guidelines on how to make ASTRO 101 more inclusive. All we can hope to do at this point is to make you aware that your class will be greatly improved if you can find ways to include astronomy as a diverse endeavor in which people of many different backgrounds engage.

Box 2.6 Principles of Good Practice

The *Seven Principles for Good Practice in Undergraduate Education*

1. Encourage student-faculty contact.
2. Encourage cooperation among students.
3. Encourage active learning.
4. Give prompt feedback.
5. Emphasize time on task.
6. Communicate high expectations.
7. Respect diverse talents and ways of learning.

Adapted from Arthur W. Chickering and Zelda F. Gamson (1987).

Chapter 3

Teaching for Understanding: Recent Results from Physics and Astronomy Education Research

Over the last two decades, our scientific community has witnessed an explosive growth in the number of scientists who are adopting research in teaching and learning as their principal area of academic scholarship. In particular, recent national conferences of the American Association of Physics Teachers (AAPT) have seen physics education research (PER)[1] presentations and PER participation go from being barely visible to dominating many conference attendees' schedules. The AAPT, with leadership from the PER community, is even publishing *Physics Education Research—A Supplement to the American Journal of Physics* to serve this community. Some of the recent results resulting from this flurry of activity have significant implications for teaching ASTRO 101; we summarize some of the most influential ones to provide the reader with a context for the recommendations in the following chapters.

Students Can Successfully Solve Seemingly Complicated Problems With No Meaningful Understanding

Although certainly not the first to present these ideas, probably the most publicized introduction to the impact of research in PER is the story of awakening told by Harvard physics professor Eric Mazur (1996). Mazur, a respected research physicist and award-winning teacher, had always enjoyed teaching introductory physics courses, found his students could

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[1] Many members of the *Astronomy Education Research* (AER) community identify themselves as part of the *Physics Education Research* (PER) community while others have called for a new designation of a combined *Physics and Astronomy Education Research* (PAER) community. For the present purposes, we use PER to include astronomy and space sciences.