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# Facts of Life for New Teachers in the Astronomy Nonmajors Curriculum

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## Abstract

This is a guide to the most pertinent or difficult practical issues that confront new teachers in the astronomy nonmajors curriculum at large colleges and universities. It covers topics such as course design and infrastructure, required effort, special considerations in nonmajors teaching, classroom performance, use of visual presentations and the Web, interactions with students, interactions with faculty research, and many details of recommended practice in the face of constraints imposed by the quality of students and the amount of institutional support.

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## I. INTRODUCTION

There is little formal preparation of new faculty for teaching undergraduates in the sciences. Some will not even have had experience as teaching assistants (TAs). From their students' point of view, this situation may not be as deplorable as it is sometimes made out to be. Most people who will ever be good teachers are good from the very start. What their early classroom performance lacks in experience and polish is often compensated by energy, enthusiasm, and temporal proximity to undergraduate culture. The burden of lack of experience usually falls not on the students but rather on the teacher, who is unprepared for the effort demanded in undergraduate teaching and who lacks good intuition for the most productive channels for that effort.

Consequently, the lives of new teachers would be made easier if they knew in some detail what to expect. In astronomy departments, they are frequently asked to teach in the undergraduate "nonmajors" curriculum. Any kind of teaching presents a host of special considerations. Paradoxically, in this case, the very fact that the courses are elementary and not intended as preparation for further study in the discipline poses major challenges for new teachers.

This is a guide to the most pertinent or difficult practical issues that confront new teachers in the nonmajors curriculum in astronomy (and other sciences). The original version of this material was a rough list of "helpful hints" that I circulated to postdocs and young faculty facing new teaching assignments in the Astronomy department of the University of Virginia. That then formed the basis of a one-hour weekly seminar class in spring 2006 for first- and second-year graduate students who had expressed a desire to learn more about "real-life" college teaching. Since there seemed to be no comparable treatment of these subjects in the literature, particularly regarding teaching effort, I was encouraged by colleagues to consolidate the hints in a form suitable for wider distribution.

I have attempted to distill my own experiences, as a professor and department chair, and those of my UVa colleagues over the last 35 years of teaching some 50,000 students between us. The implicit setting for this guide is an American research university where nonmajors courses are taught on the semester system in large lecture sections of 50–500 students. Characterizations of students are for selective public universities; they will need to be renormalized for other situations.

Although colleagues at UVa and elsewhere have, in many instances, strongly influenced the recommendations and opinions here, these do not represent a consensus view. In truth, there is little consensus about some of these topics (perhaps the first important "fact" for new teachers). So what is offered here is an idiosyncratic perspective, not all of whose components are necessarily widely shared but that do, I hope, at least derive from a coherent philosophy.

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## II. THE ASTRONOMY NONMAJORS CURRICULUM

Introductory survey courses in elementary astronomy intended for nonscience majors are among the most popular science courses in many universities, with national enrollments of 200,000–300,000 per year. The ubiquitous one- or two-semester introduction to astronomy has lately been supplemented in many programs with additional, topic-oriented courses. In comparison, majors enrollments in astronomy are minuscule, with only some 200–300 bachelor’s degrees awarded each year in the United States.

Consequently, astronomy departments invest more intellectual energy in nonmajors teaching and rely more on nonmajors enrollments to help justify their faculty staffing levels than perhaps any other discipline. This is the reason that the quality and vitality of nonmajors programs are often primary administrative concerns.

These courses are designed to improve the "scientific literacy" of students with majors in humanities, social sciences, or the arts. They are not intended as a foundation for later science courses. In most universities, enrollments in these courses are driven by area or course distribution requirements in science. They are commonly taught in large lecture sections.

As you approach a first encounter with this curriculum, a central fact to recognize is that the pedagogy of nonmajors courses is distinct from that of science majors courses of the kind that you have been routinely exposed to since you entered college. Overall expectations for both student effort and institutional support are lower.

1. Your students will mostly not have strong interests or good preparation in science or mathematics. That is, *you are being asked to teach a highly technical subject to a mass undergraduate audience that has been selected to lack the background and motivation needed to understand its technical aspects*. This is a remarkable circumstance, and there are few analogues to this situation in university teaching outside the sciences; survey courses in art or music perhaps come nearest.
2. Most universities intend these courses to be taught at a very low per-capita cost. You will typically face class sizes in the range of 50–500 students, and you will do so with little help. Many universities do not provide the staff necessary to support classroom demonstrations, regular discussion or problem sections, lab work, graded homework, or essay assignments.
3. Most of the real learning in science majors courses only occurs when students confront the material in the form of weekly problem sets and/or lab assignments. But these critical learning tools are normally not available to you in nonmajors courses; apart from the fact that departments rarely have the wherewithal to support them, students find them too burdensome. Instead, the prevailing teaching style is a "once over lightly" approach based mainly on lectures.

Responsibility for the success of a course is often placed disproportionately on the performance of the instructor—that is, you. But these external factors impose serious constraints. The subsequent discussion is intended to help you appreciate all the issues bearing on what can be accomplished in the nonmajors curriculum.

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## III. ELEMENTS OF TEACHING

The three important tasks you face as teacher of a new course are

1. Learning the subject. (Yes, as strange as it sounds to outsiders, no incoming teacher will have a sufficient grasp of the material in "elementary" astronomy courses. See Section VIII.)
2. Conveying it effectively to students so that they learn what you intend them to learn.
3. Developing and maintaining the essential infrastructure for the course.

Item 2 is the area where you can find the most advice from educational professionals. But over time, you will devote more effort to items 1 and 3, and here you will have to rely on your own resources and instincts and on models that you can find in your department or on the Web.

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## IV. GOALS

Before designing your course, establish your goals for student learning. You may or may not wish to discuss these with the class.

Thinking about your goals will help set priorities for topic selection and emphasis. The phenomenology of astronomy is so rich that you can easily lose yourself and your students in pursuing it to the exclusion of basic connective principles or overarching themes.

Remember that your students will take few other science courses. Astronomy may well be the only science to which they are exposed in college. Of course, astronomy offers many of the most interesting and compelling examples of scientific discovery at a level easily understandable by nonscientists, so it is eminently well suited for a central role in nonmajors science education.

Two ways to help put your approach to teaching in perspective:

- Ask: What do you want your students to remember from this course ten years from now? You'll realize that there's a big difference between short-term learning (the kind you judge with exams) and long-term learning. Whatever main points you hope to put across to your students are not likely to be reinforced later in their college careers. Not many bits of information are going to be retained permanently, so choose wisely and orient your course accordingly.
- Make a list of the "top 10" things that a scientifically literate person should know about astronomy.

Your goals should address the broader mission of exposing students to the nature and importance of science in general. In this context, astronomy is an example of scientific endeavor rather than an end in itself. The goals in this category may not lend themselves to easy testing or assessment.

> As an example, my broader goals for introductory courses are based on the following considerations. The sciences and their impact on society are changing rapidly, so it is not possible to teach students "all they need to know about science," certainly not in a one-semester astronomy course. The aim must therefore be to encourage people to educate themselves after college to keep abreast of the progress and consequences of modern science. My broader goals are therefore:

1. To persuade students that science is
   - Important—because science is now essential to the vitality of our civilization and our collective well-being
   - Understandable—at least at the level necessary to make informed public policy choices as citizens
   - Interesting—interesting enough to pursue at some level (e.g., *Scientific American* magazine or PBS's *Nova*) in later life for its intellectual rewards
2. To show students how science works—motivations, values, methods, main conclusions to date, important problems for the future—in the context of astronomy. To explain how science has arrived at reliable, verifiable knowledge of the physical world. To give a sense of the rate of progress of science and how it affects society. (Many such issues are best addressed in a historical context.)

Needless to say, your goals for student learning must be realistic in the context of the resources offered to you by your department, the capabilities of your students, and the effort that you are willing to commit to your course.

Some goals are excluded in the nonmajors curriculum: the goal of inspiring good scientists, for instance. Although that is an important source of satisfaction for teachers in the majors curriculum, you must content yourself with other kinds of success in nonmajors classes.

A good distillation of American Astronomical Society-sponsored workshops on goals for introductory nonmajors astronomy courses can be found in Partridge and Greenstein (2003).

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## V. CONTENT AND TEXTS

At any time, there are about a dozen textbooks that are widely used in U.S. introductory courses. These will exhibit rather small dispersion in their treatment of primary topics.

> Most teachers try to cover all of the important topics within the purview of their course. Compared with a required course in a majors sequence, however, you have much more freedom to choose topics. It may well be that you shouldn’t attempt to cover the full breadth of astronomy presented in typical textbooks. Your students might learn more, especially about the methods of science, with a more focused or selective approach.
>
> Authors and publishers make special efforts to include the latest fashionable topics, things (at the moment) like gamma ray bursts, dark energy, or the Cassini mission to Saturn. These are fresh and exciting to people familiar with the field. But from the perspective of nonmajors students, they are barely distinguishable from scores of other "new facts," such as the polar caps of Mars. You should think about the mix of frontier (or controversial) versus established science that you present and how it furthers the main themes of your course.

Textbooks may differ substantially in emphasis given to secondary topics that you feel strongly about. You may want to select your text or supplementary reading based on your own priorities concerning these. Among others, such elements include:

- Cosmic scales versus human scales; how our everyday experience shapes our naive "common sense" understanding of nature and physical laws.
- Critical thinking (logic, hypothesis testing, skepticism, standards for empirical evidence, uncertainty, synthesis, and so on). It’s obvious that students need to know that science is based on critical thinking and that you must explain what this means. However, there is disagreement over how students should be expected to exercise their own critical faculties during a survey course.
- The importance of mathematics to progress in physical science. And the independent questions of how much of the conceptual development in your course should rely on math and whether students should be expected to use math in assignments or exams.
- The incompleteness of science/astronomy: What remains to be done? What are the limits of scientific knowledge? (e.g., do we still need astronomers?)
- The distinction between science and technology. The impact of science/astronomy on technology and society. The value of "curiosity-driven" research.
- Astroarchaeology
- Astrobiology, SETI
- Earth’s climate: astronomically induced variations; human-induced changes
- Cosmic ecology: How the astronomical environment can affect life on Earth and elsewhere (asteroid impacts, solar physics and evolution, metallicity, dark clouds, supernovae, gamma ray bursts, and so on)
- The philosophy of science: social-constructionist criticism of the value and content of science; science/astronomy and religion
- Pseudoscience: for example, astrology, UFOs, "creationism" and "intelligent design"

Text selection issues:

Publishers will eagerly send you sample texts and will give you access to Web-based material for evaluation purposes. You can't simply skim a book to evaluate it, however. You must carefully read selected sections and determine whether they are accurate and thorough and how well they mesh with your teaching style and emphasis.

Many teachers object to the proliferation of new editions and are reluctant to switch texts because of the effort needed to vet and accommodate a new textbook. Better the devil you know.

Modern astronomy textbooks are crammed with about twice as much material as your students can reasonably be expected to absorb. You might find the detail interesting and diverting, but they more likely find it intimidating and frustrating. Unfortunately, at the moment, there seem to be no good alternatives to the kitchen-sink style of textbook. The best you could do would be to adopt a text intended for a one-semester course and teach it over two semesters.

It is a disservice to your students if different sections of the same course or course sequence in your department adopt different texts. This means that you must be willing to compromise on your text preferences.

In selecting any required materials for a course, one of your responsibilities is to check out the cost to students and minimize it to the extent practicable. You will be appalled at what publishers and bookstores charge students, but there may not be good alternatives.

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## VI. EFFORT

The effort that you invest in teaching a given course is shaped mainly by decisions you make before you begin: topic coverage, the nature of classroom presentations, the kind of assignments made and grading standards for them, out-of-class activities, supplementary materials offered to students, and so forth. Even outwardly minor choices regarding regular class meetings (e.g., instituting brief graded exercises) can greatly affect your total effort because they are multiplied by the number of meetings. You must also consider the extent to which extra effort now can be amortized over later course offerings.

A typical semester might consist of 14 weeks of regular class time, followed by 1.5 weeks of reading days and final exams and preceded by a few days of orientation/preparation, for a total of about 16 weeks of student contact time (not counting downtime such as Thanksgiving or spring break).

For a typical "three-hour" class, you will therefore need to plan about 42 regular class meetings for a three-meetings-per-week, 50-minute class or 28 regular class meetings for a two-meetings-per-week, 75-minute class.

If you give two in-class midterm exams, this implies planning 40 or 26 lectures or other presentations, respectively. You must make allowance for whatever special review sessions, discussion groups, lab sessions, TA training/management meetings, and so on, are associated with your course.

The essential "fact of life": *Good teaching takes much more time than you expect.*

The normal effort for the first time teaching a "three-hour" nonmajors science course averaged over the semester, is 20–30 hours a week. This standard assumes low-to-moderate enrollment in the range of 50–200 students and a light grading burden (e.g., no assignments other than objective examinations).

Expect to spend a minimum of 15 hours a week for an established course (after, say, three to four repeats), assuming that no important upgrades are being implemented.

The career-averaged ratio of total course-specific effort to in-class effort is about 7:1.

In nonmajors science courses, most of this time is spent in *class preparation* rather than, say, in grading or student conferences.

The numbers above assume good preparation by a reasonably efficient person.

The effort involved in subject matter preparation is effectively independent of the size of the class. Your total effort here depends much more on the number of different classes you teach than on their size. However, good class management and organization is much more important in a large class than a small one.

Preparation can be considerably easier in situations in which class discussion plays a prominent role or audio-visual presentations are not expected. Many humanities and social science courses are of this type, but not, unfortunately, science courses.

Some fiducials for preparation effort:

- During a standard 50-minute lecture, even allowing time for questions and brief discussion, you would utter over 5,000 words—equivalent to a 20-page term paper. Remember how long it took you to write such papers as a student? How often did you write three in a week, or 12 in a month? How many were good?
- It's well documented that it took Winston Churchill, one of the most knowledgeable and articulate statesmen of the 20th century, up to eight hours to compose a 40-minute speech for Parliament. That's a 12:1 ratio in preparation to delivery time for a simple talk on, usually, a well-worn subject. Churchill didn't have to grade essays from the MPs or edit PowerPoint files. He had two to three paid assistants. And he was smarter than most college professors.
- As a working scientist but inexperienced teacher, you might have at your disposal about five hours' worth of level-appropriate material from which you could make confident and enthusiastic extemporaneous discourses to an undergraduate class. That will carry you through two weeks of the semester—only 12 more to go!
- Think of the challenge facing an actor who must perform 40 different one-act plays over a three-month period. Then imagine having to write the plays as well. Your situation isn't quite this daunting, but it's close.

It is normal in university teaching that courses are highly individualized. Each faculty member is responsible for developing his or her own course resources: lecture notes, syllabus, reading list, visual aids, Web pages, homework and lab exercises, examination questions, grade management software, and so forth. Although your colleagues are usually happy to help you with course infrastructure if they can, this leads to a steep learning curve in the initial two or three semesters of teaching any course.

The reason for this is not indifference or a desire to be tough on young faculty, but rather the absence of a middle-management system in the corporate style. "Ownership" of courses, not to mention the creative energy needed to realize them, resides with individual faculty members, not with the institution. Because of the strong filter imposed by the tenure system, university faculties and their academic operations can be essentially self-administered. They are actually "lean and mean" by the standards of other organizations (including the central administrations of universities). Although this keeps costs down, there is no cadre of trained support personnel that you can draw on to share the burden of developing your courses.

Fortunately, the Web now offers a forum for exchange of information concerning course infrastructure that was not available before. You can inspect hundreds of posted class Web sites for samples of topic coverage and emphasis, assignments, and other details of course administration.

For good lists of helpful sites on the Web, see "Web Sites for College Astronomy Instructors" by A. Fraknoi at http://www.astrosociety.org/education/resources/educsites.html and the "astronomycenter.org" site, sponsored by the AAS, AAPT, and NSF, at http://www.compadre.org/astronomy/index.cfm

How much and what kind of effort you invest in teaching depends in part on things beyond your control.

Most important is the amount of labor that you can call on from TAs, graders, and technical support staff. Your administration will already have decided how many resources to devote to each course. As noted above, the emphasis on low costs often results in "pure" lecture courses without personnel for classroom assistance or for supplementary activities such as graded homework, labs, or discussion sections. Computerized systems are not yet adequate surrogates here.

Team teaching in larger sections, if your department encourages it, is an important way to improve efficiency and reduce duplicative effort. It can deploy the special strengths of each faculty member to best advantage. It is especially helpful in introducing new faculty to the rigors of mass audience teaching. Unfortunately, it requires a degree of organization that seems to elude most departments.

A related important external factor is classroom size. Above a threshold of about 25 students, it is doubtful that class size has much influence on the quality of a course. For the sake of efficiency, your department should secure access to the largest classrooms consistent with the overall expected enrollment. For instance, with a total enrollment of 400, it would be better to teach two sections in a 200-person classroom than eight sections in a 50-person classroom.

You have to decide how much your students can learn within the envelope of available resources, how much extra personal effort you can afford to invest in compensation for circumscribed support, and how and when to argue for better support.

It’s hard for inexperienced teachers to determine where the point of diminishing returns lies. Consult your colleagues.

Don’t be surprised if your personally written support files for a given course eventually total northward of 200,000 words (i.e., roughly textbook size). Your paper teaching records and materials will accumulate at a rate of about two cubic feet a year, or the electronic equivalent.

You must decide how much time you can afford to spend talking to individual students outside the classroom (in person, by e-mail) and then target information given to students to match.

> If you want to minimize consultation time, be sure that course requirements are clear and in writing, that lectures are clear and thorough, and that lecture summaries/notes and exam review materials are available to students. Arrive early or stay after class to answer questions.
>
> On the other hand, if you like individual contact or believe that it is an obligation of good teaching, it is easy to deliberately encourage consultations.
>
> In most departments, you are expected to be physically present in your office during "office hours" (usually three per week per class), although e-mail has greatly reduced student interest in office hours. Discussions by e-mail are usually more efficient than talking in person. You can also easily broadcast an e-mail to the whole class if more than a few students hit the same snag.

The bottom line is that *time management is the major challenge facing you as a new teacher*. Your students will mostly have no concept of the effort that lies behind what they see in class and will give you little credit for it.

> Worse, this is true of many of the overseers and critics of higher education as well. These people often have never had to deliver a single 50-minute speech in their lives, let alone 40 different ones in a semester. You will sometimes find them scoffing at the "three-hour" a week workload per course of professors. By their logic, Joe Montana earned all those millions for working only 16 hours a year on the football field.
>
> In this regard, keep in mind that students benefit, directly or indirectly, from almost all aspects of faculty professional activities, not merely from classroom teaching.

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## VII. THE TEACHING/RESEARCH BALANCE

The enthusiasm of new faculty for undergraduate teaching is often quickly tempered by the realization of how much work is involved. Nonetheless, you must invest the effort necessary to do a good job of it. Teaching evaluations from your students and/or faculty observers are important elements in faculty promotion considerations in almost all universities now. Your colleagues also expect you to carry a fair share of the enrollment burden that pays your collective salaries.

Progress in your career is, of course, also based on your other responsibilities, especially research: productivity, national/international reputation, external grant support, and graduate student research direction.

Unfortunately, most astronomers conclude that time put into undergraduate teaching is time taken away from research. There is usually little positive feedback from undergraduate teaching to your research career.

> This appears to be unlike the humanities and social sciences, in which people often claim scholarly benefits from undergraduate teaching.
>
> The main exceptions are excellent practice in making presentations, motivating and managing people, and organizing schedules, and the occasional conceptual cross-fertilization drawn from a broad-based review of textbook astronomy.

The sudden change in working style from a cocooned postdoctoral existence, in which one might devote 50 unencumbered hours a week to research, to a junior faculty appointment with many other obligations and a rigid teaching schedule is frequently a shock.

> In disciplines outside science, people often simply put off concentrated research until the summer break. But in science that isn't possible if you want to remain competitive.

The standard teaching load in physical science at research-oriented universities is one classroom course per semester, plus research direction of graduate and undergraduate students. A load of two classroom courses per semester is barely consistent with maintaining a research career in astronomy. If your institution insists on more classroom courses, it cannot realistically expect you to produce good research as well. Because class preparation is the primary effort, you are much better off teaching larger, rather than more, classes.

Many scientists find that there is a "quantum of research"—a minimum amount of uninterrupted intellectual effort that must be expended to make progress in a research program. One of the negative consequences that teaching has for research is that it will badly fragment your workweek and will reduce opportunities for moving forward regardless of how much time is nominally available for research.

> Some people find that their efficiency and creativity in both teaching and research are improved if they can concentrate all their classroom teaching for a year into one semester. But programmatic considerations prohibit this in many departments.

Faculty must also undertake service functions, some of which are onerous (another consequence of the absence of middle management). Early in your career, it's better if your service relates to a department's research activities rather than areas like undergraduate advising, graduate student recruiting, academic policies, and so forth. Needless to say, the more competent and efficient you are in carrying out service activities, the more you will be asked to do.

Be sure that you have a very clear understanding of your department's standards for promotion and expected performance in teaching, research, and service. Review this with them annually during your probationary period.

Most astronomers certainly enjoy nonmajors teaching for its own sake, accept it as a central responsibility of joining a university faculty, and strongly endorse the mission to improve science literacy. But successful faculty are clear about the distinction between the teaching and research sides of their careers and balance effort accordingly. You have been handed two full-time jobs, and you will be forced to compromise.

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## VIII. SPECIAL EFFORT REQUIRED IN NONMAJORS TEACHING

Most of the preceding discussion of effort applies to all types of teaching. But the special circumstances of nonmajors science teaching require extra preparation that will consume much of your initial effort. In fact, preparation for teaching nonmajors courses can be considerably *harder* than for majors or graduate courses.

First, much of the material in the elementary astronomy curriculum is unfamiliar to people trained as professionals. Most astronomers begin their teaching careers knowing little about history or Solar System astronomy, for instance, but these subjects are essential ingredients of introductory courses. The coverage of survey courses is inevitably broader than anyone's expertise. In many areas of astronomy, our understanding is also rapidly changing.

> Consequently, young faculty are often in the canonical fix of being "one chapter ahead of their students in the textbook" and spend much of their time simply learning the subject.

Second, regardless of your background, it is a challenge to recast your thinking to communicate with math-averse undergraduates. You and your audience inhabit different linguistic and conceptual universes, so you must continually translate your thought process into terms that they understand. This may be the hardest part of teaching nonmajors classes.

> By the time you start teaching, you have spent at least a decade learning physics and astronomy at a technical level. This is based on mathematics, which is a tremendous conceptual facilitator and shorthand. But you cannot use math in elementary courses—or at least the math that matters, which is calculus, vectors, and differential equations. Things that are immediately obvious to people who are calculus literate may take half an hour to explain to a nonmajors survey class using qualitative arguments. Contrary to popular opinion, using math makes teaching science easier.
>
> You can't assume that your students know any of the "lingua franca" of astronomy or physics, basic concepts like conservation of angular momentum, coordinate systems, quantum states, or power laws.
>
> > You can't even mention these inadvertently. One slip of words like "gravitational potential" or "acceleration vector" and you have condemned yourself to awkwardness: either you find yourself saying, "Oh...ah...never mind," implying it's beyond your audience (which may be true, but they don't want to hear that), or you're forced to stumble through an unprepared explanation. You will quickly learn the value of self-censorship.
>
> You must de- and then reconstruct every concept in terms of basic elements you have already presented to the class. Your explanations need to be much more concrete than you would use with an audience comfortable with more abstract mathematical arguments. Give carefully selected and developed examples. More difficult concepts will not be absorbed quickly: explain from different angles, reinforce, and review.

> Be aware that common terms like "force," "density," "mass," "luminosity," or "temperature" may have very different connotations for your students than you expect. You must carefully explain what you mean, but even this may not be enough to dispel internalized misunderstandings. Elicit feedback, and keep iterating.

Finally, you must devote additional time to planning special strategies to keep your students interested in and engaged with the material. Besides learning about special pedagogical methods for nonmajors students, you will need to draw on elements common to the entertainment and public relations industries but foreign to your professional training. In majors or graduate courses, you can assume a much greater degree of self-motivation in your students.

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## IX. GENERAL TIPS

In the first class meeting, clearly and thoroughly explain to your students what to expect in the course (verbally and in writing): topics covered, reading assignments, examination schedule, out-of-class work, credit system, grading scales, contact information, and so forth.

Read the textbook. You will obviously have to do that in areas in which you aren't conversant with the subject (e.g., planetary astronomy or galaxy evolution, depending on your background), but you need to do it regardless.

> Because a typical introductory course covers 300–400 pages of dense, fact-packed paragraphs, this will take some time.
>
> Good textbooks will offer good pedagogy, interesting sidelights, helpful supporting materials, and new angles on topics that you will want to incorporate into your teaching. But be alert for approaches to a subject that differ from your own. Identify text strengths, weaknesses, author quirks. Watch for errors or murky explanations. Critically inspect the illustrations and captions. Don't skip the questions and self-tests at the end of chapters, which can be bizarre. Check out any CD-ROMs or other electronic material supplied by the publisher. Ask your students for their opinions of the text.

Add some required supplementary reading other than the textbook and base several lectures on that. Be sure that the reading is appealing to laypeople. I generally use science fiction novels. Such "soft" assignments leaven the fact glut of textbook reading and help students appreciate the wider implications of science/astronomy and, in some cases, the sociology of scientists. Look for reading that humanizes astronomy.

To add depth and texture to your teaching and to find interesting or amusing anecdotes, you should read some of the good popular books on astronomy, especially on history. Numerous Web sites also provide much useful material, some specializing in science humor.

Don't be hostage to a logical topic development sequence that leaves all the "cool stuff" (e.g., the Big Bang, aliens) to the end of the semester. Distribute the more compelling topics throughout the course to the extent possible.

Be sure that there is interesting material in the first few class meetings. Resist the seemingly powerful compulsion to discuss units of measure or computations using powers of 10 in these.

Be sure, in class, to introduce any TAs or support staff with whom your students will come into regular contact.

To convey the fact that science is continually making progress, occasionally discuss interesting current events in astronomy, based on recent articles. The Astronomy Picture of the Day Web site (at http://antwrp.gsfc.nasa.gov/apod/astropix.html) features many striking images that are useful in such talks.

As appropriate, mention significant contributions to the field by your colleagues and, of course, yourself.

Make the subject as tangible as possible for your students.

Make liberal use of visual aids, computer simulations, and as many "live" demonstrations or activities as are practical to include.

It’s particularly important to encourage students to have some contact with the real night sky, assuming that you can actually see this within a mile of so of your campus. At UVa, we do that in the form of regular for-credit "constellation lab" and telescope viewing sessions.

If you can arrange a tour of state-of-the-art research facilities (image processing, instrumentation labs, shops, telescopes, and so on) for interested students, do so.

You may have to lobby your department to provide better support for demonstrations and out-of-class activities.

Personally conduct an out-of-class night sky viewing session at least once during the semester. Students greatly appreciate this kind of contact with professors.

Offer students credit options. Anything labeled "extra credit" is appreciated entirely out of proportion to its likely impact on their grades. The CLEA labs (http://www3.gettysburg.edu/~marschal/clea/CLEAhome.html) and other Web-based or CD-ROM-based exercises fit in well with extra or optional credit schemes.

Don’t require attendance at lectures. About 30% of students infrequently attend lecture classes and will resent required attendance; their negative attitude can affect others. You can strongly recommend attendance and award some small extra credit for that (say, 5% of the total), but don’t push the point. Let the absentee students mess up; that’s part of their learning experience. (On the other hand, if they do well, then they evidently made the right choice!) You will have a more appreciative audience without them.

Important student self-selection tip: advertise other suitable courses that you teach, especially in the following semester. Those will be better as a result because you will attract those students most attuned to your personality and teaching style.

You will probably be energetic, well prepared, and enthused at the beginning of a semester, but none of these at the six-week mark. That’s a good time to plan some kind of change of pace that conserves your preparation effort and sanity: guest lectures, student debates, a full-hour discussion of a novel, videos, a substitute nighttime observatory session, a full-hour lab exercise, a Web tour of Hubble Space Telescope

(HST) pictures, and so forth.

Your own attitude, values, and demeanor are actually important educational elements in these courses. Because your students will rarely, if ever, encounter active scientists in later life, for them, you are a principal representative (and role model) of scientific enterprise and culture.

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# X. YOUR STUDENT TARGET AUDIENCE

At what student ability level should you target your course? Here are the considerations and my advice.

The most striking feature of the student population in large nonmajors courses is its incredible range of interests, abilities, and attitudes. All your students may have decent paper credentials from high school, but they will vary tremendously in their intellectual motivation and skills. Remember that all those students with strong science, math, engineering, or pre-med interests are not candidates for these nonmajors classes to begin with. On the other hand, among your students may be some who will achieve success as teachers, historians, artists, novelists, diplomats, lawyers, corporate executives, or lawmakers.

> The top 30% of your class at a selective public university will be bright, interested, well-motivated, responsible, and (mostly) appreciative of what you do. They can perform up to any reasonable expectations for a nonmajors course (i.e., they are the kind of audience you probably are expecting).
>
> The bottom 30% will be the converse. They are in the class for many reasons, probably starting with an area requirement, but a strong desire to learn about astronomy isn’t one of them. They often lack good academic skills. Some are looking for an easy grade (they are usually misinformed about this). Some are simply incorrigible (if occasionally amusing) slackers. In various proportions, the bottom 30% won’t be interested in the subject, are self-absorbed or easily bored, aren’t motivated to work hard, can’t think their way through difficulties, can’t learn easily from the textbook, won’t follow simple directions, will ignore your good advice, or will radiate bad ’tude.

There is considerable controversy among astronomy teachers as to how inclusive your teaching strategy should be: that is, what fraction of your students should emerge having met the basic learning goals you set for the course?

My advice: You can’t please all the people all the time, and you shouldn’t try. *Aim your course at the best 60%*.

> It’s hard to reach the least motivated or capable people. Your goal should be to retain the interest, respect, and enthusiasm of the better students while still helping the others to learn. (Nobody said teaching nonmajors classes would be easy.)
>
> You can make it a private crusade out of the classroom to rescue and motivate poorer students, but you don’t want to bore or irritate the good students by pandering to the others in class.

Steven Weinberg (1977) adopted a good fiducial approach in his best-seller, *The First Three Minutes*: "I picture the reader as a smart old attorney who does not speak my language, but who expects nonetheless to hear some convincing arguments before he makes up his mind" (viii). You might take that as a baseline and then dial it back a couple of notches.

Determining the target audience for a course is one of your key strategic decisions, on a par with deciding your learning goals. It will determine how your course is structured.

> A successful design for the top 30% can differ considerably from one for the bottom 30%.
>
> Always evaluate discussions of teaching reform in the science education literature in the context of the intended target audience.

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## XI. INTERACTIONS WITH STUDENTS

Establish a good tone in the first 15 minutes of the first class meeting—enthusiasm, interactivity, humor, accessibility, accommodation of student interests, and so on. Get students to respond to questions or involve themselves in a discussion quickly.

It’s very useful to survey the student terrain by passing out a questionnaire during the first meeting that asks for their backgrounds, interests, expectations, and topic suggestions for the class. Students will also appreciate your interest in their views.

Do a written midterm course evaluation to see how things are going.

Offer an anonymous feedback Web site, if feasible. This is unlikely to generate fulsome praise, but it does give you some longitudinal information on discontent.

Classes have personalities. It helps to have a few bright, outspoken, funny students who become "leaders" (as long as they are supportive of what you’re doing!). Encourage them.

Empathy with students, if it comes naturally to you, is a good thing and will smooth your interactions with them. Remember, however, that your job is to be a teacher, not a pal. Don’t allow your feelings for students to compromise your standards.

"Accessibility"—that is, being available for consultation and responsive to student concerns—is regarded as a key virtue by students.

> Remind students of your office hours and how to get in touch with you. Respond to student e-mail quickly.

A hard lesson for teachers in nonmajors courses is that it is, unfortunately, rare for a student to come to you concerned about intellectual content. Most of those who want to talk with you are concerned with grades, and most of your time talking to students will have such a focus. Another hard lesson is that the majority of the individual attention you give students will involve the bottom 25% of the class. Some of these are people who genuinely need help in learning how to learn. Most astronomy professors can’t provide that; instead, consult your dean’s office about referral to trained tutors.

In one-on-one interactions, it's important to always be on your best behavior. As long as students are trying to do the right thing, you should be friendly, helpful, encouraging.

If this is difficult for you or if you prefer to avoid personal interactions, then be sure to follow the tips above on making standards and expectations clear, holding exam reviews, and so forth.

You should certainly try to remember the names and backgrounds of students with whom you personally consult. Some people have the politician's gift of being able to rapidly memorize names and faces and can do so even in classes of 50—100 students. Don't despair, however, if you are among those who have trouble remembering the names of their own children. Name recognition produces a warmer atmosphere but is not essential. Substitute a smile.

Give the benefit of the doubt to any student who seems to be trying—whether by regrading ambiguous work, extending deadlines, or allowing late exams. The stakes are small enough (Astronomy 101 isn't prerequisite to the Supreme Court) that it isn't worth being hard-nosed. But make such exceptions in private conferences.

Be understanding. The flurry of grandmother expirations just before a midterm exam may be artificially inflated, but a certain number of students every semester are hit with unfortunate circumstances beyond their control. (Some will let you know this; others won't.) Never be sarcastic or dismissive.

Under no circumstances entertain romantic notions toward any of your students.

But: Don't feel bad about being firm with manipulative, irresponsible, or dishonest students. You will encounter a number of these. They do not make your day.

Academic cheating is a major problem. Even at schools like UVa with vigorous honor systems, surveys show that perhaps 20% of the students are occasional cheaters. The figures are worse in most universities.

Your life is much easier if you can assume that most students are honest, because you don't have to worry about intrusive exam proctoring, checking student IDs, mandatory seating charts, making up multiple versions of exams, and similar tiresome security measures. These can easily double your exam administration effort.

The current fashion for cheating during exams is to use electronic communicators. Forewarned is forearmed.

Be clear about your policies on independent out-of-class work and the meaning of honor pledges.

A cheating accusation is a serious matter, so be sure the evidence is solid. Talk to the students involved. If you have convinced yourself that cheating has occurred, the principle of academic freedom should permit you to apply any reasonable sanction, up to failing students in your class. However, your university may have policies that circumscribe your options. Ask for advice.

Written student course evaluations (almost always anonymous) are now routine at most universities and become part of faculty employment records.

For better or worse, there is no doubt that many faculty shape their courses to encourage better student evaluations.

There is an entire literature on this subject and the extent to which student evaluations can be objective and informative assessments of teaching. Controversy abounds here, and you will want to learn the opinions of your experienced colleagues, especially those who will consider your promotion.

Most of my colleagues have concluded that good course evaluations are neither necessary nor sufficient to demonstrate good teaching and student learning. Systematically below-average evaluations are, however, something to consider carefully and seek counsel about if they persist.

> Good evaluations may themselves be a goal of your institution as a measure of consumer satisfaction, especially now that Web sites like *ratemyprofessor.com* have sprung up.

Evaluations usually contain both multiple-choice and open-ended comment questions. The latter are often more valuable. Comments from thoughtful students can contain good suggestions to improve your courses.

Study the formulation of your department's course evaluation survey and decide whether it covers the areas of importance to you. It may emphasize teaching more than learning, for instance, and you may want to know the answers to questions like, "Did you learn most of what you wanted to learn in this course?" "How confident are you in your understanding?" "What did you not learn that you wanted to learn?" "Why didn't you learn it?" Questions should be framed to encourage helpful responses, for example, "Please make constructive comments on how this course could be improved."

If you can, add such special questions to the standard survey form. Otherwise, you can circulate your own survey to your students (though evaluation fatigue must surely be setting in among our student population).

Critiques by faculty members, graduate students, or other professionals who are asked to sit in on several of your classes are likely to be more useful in improving your teaching than are student evaluations.

Be sure you get complete copies, or accurate summaries, of your evaluations.

In the final analysis, how much do you (the teacher) really matter?

Most faculty I know subscribe to the point of view embodied in the following Chinese proverb:

> *Teachers open the door. You enter by yourself.*

Teaching isn't the important thing, *learning* is. These are distinct functions, though they are often conflated by critics. Learning must be done by the students; teachers can't do it for them. Teachers provide conceptual foundations, advice, structure, discipline, encouragement, inspiration, incentives...but students, certainly at the college level, must take responsibility for their own learning.

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# XII. ASSIGNMENTS, INNUMERACY, QUANTITATIVE WORK, CRITICAL THINKING

### A. Expected Work

The traditional rule of thumb for expected out-of-class effort by average college students is 2 hours of work for every hour in class, or six hours per week for a "three-hour" course.

> Modern students, however, seem shocked and amazed by this suggestion, and few are prepared to invest "so much" time in a nonmajors subject. Their expectations for the workload are low, no more than two to three hours of out-of-class work per week.
>
> This poses a fundamental dilemma for the kind of elective nonmajors courses that we are discussing: comprehension requires exertion by students, but if you cross an invisible barrier in expected work, they will simply stop enrolling in your course. To be effective, you will have to figure out how to push the envelope of student expectations without driving them away.

Be completely clear about expected student work in the course. Discuss each required or optional assignment and the credit available for each.

Typical expected work in nonmajors courses might include two "midterm" exams, a final exam, and some optional out-of-class work. If staffing is sufficient, there are weekly discussion sections or lab/observing sessions with graded homework or in-section exercises. Exams usually carry at least 80% of the course credit.

If there is no requirement for weekly graded work, the natural tendency of students will be to wait until just before an exam to do any studying. This is a serious difficulty and is good neither for comprehension nor retention. There are several approaches to encouraging your students to regularly confront the material without depending on a large contingent of support staff:

> Design for-credit activities in class that are based on preclass preparation. For example, give a short quiz at the start of each class, or employ the kinds of exercises described in Sec. XV(I) below. The grading burden here can be mitigated with computerized grading or electronic response/recording systems.
>
> Offer extra-credit, out-of-class work in an "open laboratory" format, in which labs are staffed at regular times but student attendance is optional so that relatively few support personnel are needed.
>
> Offer credit for timely completion of out-of-class computer-based exercises. There is a rapidly growing body of Web- or CD-ROM-based tutorials and exercises intended for nonmajors classes; some from textbook publishers support automated grading. An excellent example is the set of tutorials hosted by Pearson/Addison-Wesley. Such exercises can be very helpful in clarifying basic concepts, including quantitative analysis. (You should refer your students to the good ones whether for credit or not.) You must, of course, be prepared to answer questions about them in class.

> Instead of the standard one or two "midterm" exams, you could give four or five shorter exams. This encourages better engagement but reduces the content that you can cover and increases the grading burden.

Important tip on student psychology: No matter how emphatic or frequent your exhortations, students will almost always wait until what they judge to be the last possible moment to start doing an assignment. They often underestimate the effort needed.

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### B. Science Literacy and Innumeracy

Many of the students in the nonmajors curriculum are uncomfortable with science, and few will be science literate at the level of an entering science major. Most will have a poor background in physics. They will have no astronomy background beyond a possible eighth- or ninth-grade introduction (mainly planetary) in an "earth science" class.

> Consequently, it is best to assume that your students remember little about science above the ninth-grade level. Even those with better science backgrounds will probably appreciate a review of the basics.

> Your students will harbor various expected (and some unexpected) misconceptions about astronomy and physics. For instance: The Sun is on fire; the stars aren't there in the daytime; the stars don't rise or set; there is no gravity in space (as demonstrated by free-fall on orbit); spacecraft move only when their rocket engines are on; heavier objects fall faster; constellations have physical significance; there is some validity to astrology; meteors are falling stars. They will grossly underestimate the scale of the Solar System and Galaxy. Some will subscribe to a quasi-creationist view of life on Earth. Even if they readily accept that Earth is 4.5 Gyr old, they will have no quantitative concept of what that implies. Most will have no appreciation of the extent to which basic scientific research has affected their lives. See Zeilik and Morris (2003) and Comins (2001) for more details on common misconceptions.

Most of your students can understand important scientific results and the evidence/logic employed in reaching those. But, apart from the best 20%, they cannot be expected, on their own, to reason their way to meaningful scientific conclusions not already presented to them. Neither their knowledge of the facts nor quantitative intuition supports that.

Innumeracy is endemic among students taking nonmajors science classes. Remember that most will have below average mathematics ability. Don't expect anything but minimal quantitative grasp. Your students may not remember even basic math concepts or how to apply them (e.g., how the volume of a sphere is related to its radius). Some are baffled by an inverse square law or an x-y plot. Tangents or logarithms? Don't ask. Older students (further removed from high school) will remember even less than first-year students.

> Because math is taught in isolation from other subjects in most secondary schools, students can have good facility with it but still have trouble applying it to new situations, (e.g., in astronomy).

Don’t ask students to assess their own facility with math. Most will be reluctant to admit that they are uncomfortable with it, and many aren’t aware of their own innumeracy. Give a no-credit preliminary assessment test if you want a clearer idea of how well your students can handle quantitative work.

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### C. Critical Thinking and Quantitative Reasoning

Given this fundamental deficiency, what should you expect from your students in the way of quantitative reasoning or "critical thinking"? There is no consensus on this matter among astronomy teachers. Here is my opinion:

> To hone thinking skills in students, teachers must be able to interact with them on an individual basis. Therefore, my view is that without a cadre of trained TAs/tutors who can help students with basic math and scientific reasoning and who conduct weekly small discussion/lab sections, it is next to impossible to make much headway against innumeracy or improve critical thinking skills in a large nonmajors course.
>
> With such resources available, you can offer quantitative elements and critical analysis in the form of regular graded homework and in-section exercises that are guided by TAs. Plan on a minimum of one TA for every 60–80 students meeting in one-hour weekly discussion sections (20–25 students per section).
>
> Without such resources, there are more productive ways to spend your class time than trying to teach quantitative thinking. You will have enough trouble making sure your students are comfortable with those quantitative elements that you cannot avoid using, such as x-y plots and perspective diagrams.
>
> > Hand out notes on the math that you will expect students to understand.
> >
> > Most students are aware of "powers of 10" notation, but they will not be facile with it; you must provide a refresher.
>
> In either case, it’s best to base exams overwhelmingly on qualitative knowledge. An expectation for quantitative effort on exams (simple computation, equations, or the dreaded "word problem") will instantly force most of your students’ attention and concern to computational skills to the exclusion of other content. I believe this is a mistake in nonmajors classes because it detracts from the science.
>
> > It is unfair to your students if you expect computations on exams but have not assigned comparable for-credit, graded homework exercises.

It is emphatically untrue that "nonquantitative" astronomy is "dumbed-down" astronomy. You can offer many sophisticated insights and challenging concepts in a nonquantitative course (think of teaching the philosophy of Heidegger). It’s just *harder to teach* than if you were able to use math freely.

I believe the best way to assess and encourage student reasoning and critical thinking is not in a strictly scientific or quantitative context but rather in a cultural or historical context, where students have better intuition and backgrounds. Good critical thinkers aren’t necessarily good at quantitative reasoning.

Have students do research and write papers. Ask for writing that emphasizes analysis rather than description. There is a wealth of good potential paper topics on the impact of science on society, historical and prehistorical astronomy, the philosophy and morality of science, the value of government support for science, the "two cultures," pseudoscience, and so on.

But don't have students write papers on technical topics such as how supermassive black holes drive nuclear activity, or why planets have rings, or what degeneracy pressure is—you will be very unhappy with the results in 80% of the cases. By having to point out the inevitable gaps in students' technical understanding, you may actually be discouraging their interest in science.

If you are serious about improving critical thinking skills, you should ask for and approve a brief summary and bibliography from each student before they begin writing, and you will obviously have to evaluate more than one writing assignment.

Writing papers is undoubtedly good for your students. However, grading papers in a large class is very demanding (see below).

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### D. Assessments of Student Learning

The traditional approach to assessing learning involves written examinations, homework/labwork, and papers. Papers were just covered, and I discuss exams in the next section. A broader array of teaching/assessment techniques have recently appeared, mostly intended for use during lectures. Some of these are briefly discussed below under Classroom Performance, but a more complete description can be found in Brissenden, Slater, and Mathieu (2002) and at the Field-Tested Learning Assessment Guide Web site (http://www.flaguide.org/intro/intro.php).

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## XIII. EXAMINATIONS

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### A. Tips on Exams

Schedule the dates and coverage for each exam at the beginning of the semester and then stick to that schedule. This is part of an implicit contract with your students. Don't schedule exams adjacent to holidays.

On true/false or multiple-choice questions, allow students to explain their answers (in writing during the exam) if they think your question is ambiguous, and give credit if they show they understand the subject. You will be surprised at the bizarre ways in which students can misinterpret questions.

Hold a review session for each exam, in class or out. Encourage questions, or base the entire session on questions. To promote better study habits and consolidation of the material, it's better to do this several days before the exam.

Post or hand out a list of topics that students are expected to know for each exam. Examples of exam questions (and answers) from old tests are greatly appreciated.

> Because modern astronomy textbooks are overflowing with detailed but subsidiary information, especially in the form of tables and illustrations, you also need to tell your students what topics to ignore(!).

Always go over exams in detail in class when you hand them back. Explain the answer for each question, explain the grading, show a score histogram, interpret numerical scores in terms of letter grades, ask for questions. This is important both for addressing grade anxiety and also for helping students learn from their mistakes. Be sure to identify areas where students had particular difficulties for special discussion. Tell students to add up scores for themselves to be sure there was no arithmetic error. Always be willing to regrade in the case of apparent grading errors.

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**B. Style**

Typical midterm exams might have 40–80 objective (true/false, multiple-choice) questions plus additional brief answer, fill-in, or essay questions.

I think that well-designed multiple-choice tests with a small number of nonobjective questions can test student understanding at the nonmajors level almost as well as any other written format.

Better for testing comprehension would be sets of brief answer (say, one paragraph) questions starting with "How," "Why," "Explain," "Interpret," "Compare," and so on. The formidable problem here is the burden of grading perhaps 2,000–3,000 brief essays for each exam.

The best tests would be oral exams, with an opportunity to iterate in areas in which a student has difficulty. But that’s not feasible in large classes, and it’s hard to make oral exams uniform and "fair" (i.e., such that you wouldn’t get regular complaints about low grades).

"Pop quizzes"—occasional brief, unannounced for-credit exams—are a good way to encourage students to keep up with the material and come to class. They can be very revealing about student comprehension and study habits, but they will not be well received—unless they count only for extra credit.

Professors differ on whether the final exam should be cumulative, whether it should receive high weight, or even whether it is required (some offer alternatives such as research papers). Students can learn a great deal in consolidating ideas as they prepare for a comprehensive final; on the other hand, there is no real opportunity to learn from their misconceptions or mistakes.

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**C. Preparation**

On subsequent offerings, you should assume that many of your students will have access to your old exams from the past few years. Whether this actually conveys an advantage is a matter of debate, but out of caution, most people make up new exams each semester. Over time, you can accumulate large digital files of exam questions from which it is straightforward to generate new exams. It’s easy to change the essay-type questions, harder for the objective questions.

Exams should accurately reflect the things that you emphasized in the course at a comparable level of difficulty and should be formulated in a straightforward manner (as opposed to "tricky" or "picky").

> If you use automated grading systems, you may get a statistical analysis of which questions from earlier exams were best at testing students' understanding.
>
> Double-check the content of the draft exam against the list of important topics you made available to your students.

The questions must range in difficulty, with the hardest ones challenging even the best students. More advanced questions should emphasize analytic skills or conceptual synthesis.

> I object to the tendency to deprecate the role of memorization by students. No student who lacks the skill to absorb, organize, and retain large amounts of information can expect to understand a technical subject or succeed in a profession, whether as a teacher or a stockbroker. So, I have no qualms if exams in elementary courses emphasize memorized factual content over higher cognitive facilities as long as they do indeed test both and also focus on the main issues.

One example of unexpected effort: Although it sounds simple, making up good objective exams (true/false, multiple choice) is actually difficult. It's hard to design multiple-choice questions that meaningfully test comprehension yet offer realistic alternatives. Avoiding ambiguities in true/false questions takes work. You end up needing at least three times as many questions as you use in any one semester. One reason is that for the more important topics, you must create questions with a range of difficulty, from obvious to challenging. Another is exam security, mentioned above.

None of my colleagues finds the test questions supplied by textbook publishers to be satisfactory, so you cannot rely on those as a shortcut. Good exams must be customized to your particular course.

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**D. Feedback**

Exams provide essential feedback both to the students and to the teacher. The exam score histogram will tell you how well the test was designed from the point of view of ranking students' performance. I think it should be broad and smooth, with few students below 65% or above 95%. It may well not be Gaussian, instead featuring an extended tail to lower scores (representing mainly those who don't come to class or don't care).

You should study the congruence between the results of each exam and your goals for student learning: Did the students perform as you hoped, especially on the key topics? If the histogram is badly skewed to low scores (below 70%), then your students are not comprehending the material at the level you expect. You need to revise your presentation of the material, assigned exercises, or your formulation of the exam. A surfeit of high scores could be a sign either of great success or of low standards.

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# XIV. GRADING

Grading can be very demanding and can absorb much of your energy, possibly compromising other aspects of your course. Think carefully about the most effective balance of effort here.

In a small class setting, grading of student work (e.g., essays and problem sets) is a crucial part of education and arguably your most important responsibility as a professor. As class size grows, however, personalized grading becomes impractical; somewhere below the lower boundary of typical nonmajors enrollments (50 students), it is necessary to farm out grading to assistants, switch to simplified types of assignments, and/or go to automated grading systems.

"Objective" exams (multiple choice and true/false) dominate in large introductory classes because of the grading burden of the alternatives:

> Rough rule of thumb for grading essays (on exams or as papers): five-minute overhead plus one minute per page.
>
> > The overhead includes the time necessary to establish grading standards (this requires sampling a number of papers), time for writing comments/corrections, and allowance for saturation/fatigue with a large class. Because there are often no "right" answers in this context, you must also devote more time to conceptual analysis of students' ideas.
>
> Rough rule of thumb for grading a page of objective questions: 30 seconds.
>
> Most teachers include short-answer or brief essay questions in addition to objective ones on exams, but these will consume a disproportionate grading effort.

Typical semesterly grading effort with three predominantly objective exams (in the absence of computerized grading): 20–30 minutes per student. This implies more than 50 hours of grading (six working days) for a class of 150.

Grade recording and administration is a nontrivial effort and you must consider that in deciding the number of assignments. Simply adding an expectation for one brief pass/fail assignment a week in a class of 150 students could lead to 10–20 hours of extra administrative time during a semester unless grade recording were highly automated.

It's simplest to maintain grades in numerical form during the semester and convert to a letter grade only at the end of the course.

It is essential to be completely clear about grading standards and the expected percentage of students with a given final letter grade.

> Establish your grading standards to comport with your chosen learning goals and target audience. What grade will you assign to a student who has met your basic learning goals for the course? How much better comprehension should earn the highest grade you can assign? What fraction of the basic goals must a student master in order to "pass" the course (nominally, a D- grade)?

Will you grade on an "absolute" basis (e.g., 92% on any assignment is always an A- grade) or on a "curved" system in which the letter grade is assigned on a percentile basis with respect to the performance of this particular group of students?

If you grade on a curve, it is important to explain what this means. Most high schools assign grades on an absolute basis.

Most astronomy faculty I know use curved grading aimed at an average grade of B-/C+ (around 78%–82%). But be aware that grading standards in many nonscience courses (and at certain elite institutions) are much more generous. Most students are accustomed from high school to receiving good grades and are shocked the first time they receive a B- or lower in college.

Even though I use an adjustable curve, I’ve found it helpful to guarantee maximal numerical breakpoints in advance for A-, B-, and C- final letter grades. This helps students track their standing. This approach works only after you’ve calibrated student performance over several semesters.

If you use graders, give them explicit written instructions on what you want. Sloppy or inconsistent work by a grader will cause you endless headaches. Uniformity of grading is a key consideration, especially on essay assignments. If you don’t plan to grade essays yourself, you may need to recruit mature graduate students as graders.

Keep grade records computerized: use spreadsheet software or self-written programs utilizing ASCII files. Sorting and histogramming utilities are very useful when establishing a curved letter grade scale. (I use IDL for processing grades; many people use Excel.) Your university presumably offers a means of downloading class rolls and uploading final grades. Have your gradekeeping infrastructure well developed before the first grades come pouring in.

Use automated grading for the objective parts of your exams. The most widespread current technology uses penciled-in Scantron "bubble sheets" for answers, which can be run through computer scanners. Data are returned digitally and can be easily loaded into your electronic gradesheets. Most Scantron software provides a useful statistical analysis of the answers to each question.

It is important to provide space for students to put duplicate answers on the original exam papers, because you will want to hand these back and discuss them in class.

You can add brief answer, fill-ins, essays, and so on, but you then must arrange to manually grade those and combine the scores from the two parts. Some Scantron forms have space for brief answer or essay questions on the back and allow combination of the manual and automated grades.

Fully computerized administration and grading/recording of homework exercises, tutorials, and exams have been anticipated for some time, but well-developed and adaptable systems have yet to emerge. Some of the publisher-supplied Web-based exercises offer automated grading.

You should post grades as each assignment is graded. Many departments offer a secure, password-protected Web site to report grades to students. (Federal law now prohibits public posting of grades where there is any possibility that individuals can be identified by others.)

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# XV. CLASSROOM AND LECTURE HALL PERFORMANCE

The imagined setting for the following comments is a lecture hall for 50–500 students. However, many of the items in this section apply to all teaching activities, regardless of whether these are in the form of traditional lectures.

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### A. General

In many areas of teaching, it's easier to know what to do than to actually do it, and that is no more true than in classroom technique. It is difficult to experiment in front of a live audience, and the pressures of preparation and schedule will often circumscribe innovation. Teaching may have much in common with professional theatrical performances, but each class meeting is from a different script.

To complicate matters, there is presently considerable controversy over the effectiveness of different classroom teaching styles. The traditional "pure" lecture format has come in for particular criticism. Although I tend to think that both its shortcomings and the benefits of reform have been overstated, there is no question that special efforts to promote dialogue and engagement with students during lectures are worthwhile. An interactive teaching style also helps you make best use of your classroom time because you can assess your students' comprehension in real time and reorient your approach to address difficult points.

However, the burden of promoting a good classroom experience is not yours alone. A fair share of it falls on your audience. Any teacher-student interaction is a two-way street.

> Responsible students will have done the reading and other assignments before coming to class, will listen and participate carefully and seriously, and will know when they should raise questions for clarification. The more such students there are, the better the classroom atmosphere will be.
>
> If students had to shell out in cash at the classroom door the $20–$60 that a single lecture is effectively costing them (and/or the taxpayers), the minds on both sides of the lectern might become more strongly focused. (Professors in big nonmajors courses would also be astonished to learn how little of that money ever shows up their paychecks.)

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### B. The Limits of the Classroom

You should not think of the classroom as the primary learning environment. The most effective teaching medium ever invented is the book. Classroom teaching, whatever the form, is at best a distant second. Not even excellent students can fully comprehend a technical subject on the basis of classroom exposure alone, and the more nuanced the material, the more dependent are students on written explanations or exercises. Despite your best efforts, it is much easier for students to misunderstand in the classroom than in studying from written material.

Consequently, your main role in the classroom is to act as a guide and facilitator—to distill and clarify the basic concepts, principles, and facts that students read about in the text or distributed notes. However, it is important that you also emphasize things that they will *not* encounter during normal study: visuals, demonstrations, experiments, animations, guided exercises, discussions. The motivation that you provide from your attitude, energy, and enthusiasm may be as important as any other aspect of the classroom experience.

You must take special pains to be clear and thorough if you are presenting material or perspectives that are not well covered in the text. Here, I strongly urge you to provide supplementary notes or other take-away material.

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**C. Scope**

One of the hardest lessons for new teachers to learn is how little material can be presented successfully in a single class meeting. This is so counterintuitive that seemingly half of all experienced scientists have never been able to absorb it (judging from the typical colloquium). Your beginners' intuition will overestimate viable lecture content by a factor of about three.

Only about three to four key ideas can be presented in a lecture, and the key points need to be stated at least twice each.

It's better to plan to deliver less material than more. This will, for instance, make you focus on the main issues. Beware the tyranny of overpreparation.

Deliberately plan the pace of each class:

> Adjust the pace to the rate at which your students can absorb the new material. This varies with the subject matter.
>
> If you don't provide copies of lecture notes, many students will try to write down everything you present on visual aids or on the chalkboard. This acts as a significant drag on your presentation. Making lecture notes available to students is the best way of streamlining the presentation and relieving the stress. See comments in Sec. XVII on this subject.
>
> Regularly check a clock for timing. Never, ever go over time (50 minutes for three-times-a-week lecture, 75 minutes for a twice-a-week lecture.)
>
> If you run short of time, don't force the pace; rushed presentations are virtually guaranteed to be poor. Cover the leftovers in the next lecture or ask the students to pick them up from the text or lecture notes. Give the important points in the introduction and summary.
>
> Always set aside enough "space" in a presentation for student questions and comments.
>
> Remember that "the secret of being boring is to say everything."

There are various ways to structure a lecture course.

The traditional approach is to assume that students are seeing the subject for the first time, so that lectures introduce the subject.

Instead, for instance, you might require your students to have read the text and lecture notes ahead of time. Then go through material as if it is a review of key issues, say, in 20 minutes. Then foment discussion of difficult points or interesting sidelights; show relevant demos, images, videos, or Web links; or host class activities.

The main concerns about this approach: Students who don't do the advance reading will be lost, and you may feel irresponsible if you don't present the topic completely. Even the best students can't always find the time to keep up on a regular basis.

Another approach: Alternate class meetings between standard lecture presentations and sessions devoted to demonstrations, in-class exercises, and so forth.

Establish a lecture schedule at the beginning of the semester and stick to it unless you're willing to drop whole topics if you get behind (both from lectures and from exams).

Don't allow more than about one lecture of "pushback" or you'll fall behind seriously. This is more challenging than you think. It's a good idea to deliberately schedule slack lecture periods to occur about two-thirds of the way through the semester, allowing time to catch up for the inevitable lag.

Off-the-cuff discourses on some extra-syllabus topic of interest to students (but that is somehow connected to the course and that you have thought and can be enthused about) can be very well received. This is a good way to fill up some time if you haven't prepared enough material. It's probably not good to do this regularly, however, because the serious students will get restive.

Students appreciate hearing something about your professional career: current research, observing runs, mechanics of funding/grants, foreign travel, how you got interested in astronomy, education/training, and so forth. These are good subjects for one or two short "off-the-cuff" talks each semester. Show your students actual proposals, papers, data, snapshots from meetings, and so forth; personalize your science.

Warning: Students do not like to hear political views of professors on topics not directly related to the subject, although occasional jokes at the expense of politicians are welcome.

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**D. Performance**

Classroom teaching is a performance art. Some people are naturally inclined to that, others aren't. There is no correlation between your abilities as a scholar and your talents as a performer.

Teaching large introductory courses, in particular, is a form of show business and presents many of the same on-stage and off-stage considerations.

It is actually something of a specialty. The reality is that many otherwise capable young faculty are not well suited, either by their personalities or their philosophies of education, for the exigencies of mass undergraduate teaching. But astronomy departments normally don't have the luxury of assigning large classes only to those faculty who enjoy working in this arena. If you lack a flair for performance in front of a large audience, you will have to work harder.

*Good preparation and notes are essential.*

Orchestrate the shape and timing of each class. Whether or not you write out a detailed plan/script, you need to know what you will be doing at each point in the presentation, how you will phrase the important issues, and how you will incorporate the chalkboard, visual aids, demonstrations, or class activities.

It's best to have a firm mental picture of the whole presentation at your disposal so that you rarely need to refer to notes.

In a first-time pinch, notes could be generated from your digital presentations—but you will find that you need much more careful notes in the long run as you refine your teaching and try to minimize subsequent preparation time.

Be sure that your presentation is well structured conceptually so that your students always understand the context and connections between its parts. This helps establish a mental template for understanding the material.

Be sure that your presentation of the main issues is clear and thorough but free of extraneous elements.

Have a good set of concrete examples and illustrations prepared for each important concept (if appropriate).

Be well organized administratively: make timely announcements regarding assignments, deadlines, and other factors bearing on student grades; have handouts ready; return graded work promptly; track areas where students are having difficulties; and so forth.

Sequencing

Always plan an introduction to each class in which you give an outline of the presentation and place it in the overall context of the course.

I recommend that you make lecture notes available before each meeting, but if you don't wish to do that, you should at least post an outline.

Begin the actual presentation with an arresting element (anecdote, fact, opinion, image) that acts as a preview and attention-getter for the talk.

Structure your talk like you would a written paper, with clear transitions and "topic sentences" for each new section and a summary and conclusion at the end.

Be sure to motivate the coverage of any difficult or involved subject beforehand. Repeat key points. Explain complicated ideas in alternate ways.

Link points to earlier and later classes, reading assignments in the texts, Web materials, and other class activities.

Recap main points at the end of the lecture. Remind students of assignments for the next class.

Classroom technology

Good planning is essential for properly organizing multi-media presentations (slides, PowerPoint, Web, chalkboard, viewgraphs, demonstrations, and so forth).

Examples: Do you know how to blank the video projector in order to switch temporarily to viewgraphs or the chalkboard? Have you preloaded the different software (displays for PDF, PPT, HTML, or DVDs; simulators) that you will need on your computer so that you can make seamless transitions? Do you have that extension cord to power your electrical demonstration apparatus? Are you sure that video will play properly on the classroom computer? What are you going to do if one element (e.g., the video projector) fails?

Using electronic presentations or demonstrations means that you will have to be at the classroom 10–15 minutes before the scheduled starting time to be sure everything is functioning. After class, it will take 5–10 minutes to shut down and stow equipment properly.

Note that such activities, plus travel to and from the classroom, can easily soak up over 90 minutes of extra time each week, or over two working days in a semester, per course.

See Section XVI below for other comments on projected presentations.

Real-time rehearsals are the best way to be sure that important lectures, or parts thereof, go smoothly.

Make it a point to determine (from feedback from students or faculty observers or from critical self-assessment) whether you need rehearsals.

The famously extroverted and incisive Richard Feynman is said to have rehearsed his landmark lectures in introductory physics at Caltech in real time, including the jokes and chalkboard entries.

You must rehearse demonstrations, or you will be sorry. Aside from having to deal with physical reality during demonstrations, it is difficult to consult notes.

Learning a new vocabulary is an essential part of education in any subject, particularly a technical one. Give clear and precise definitions for technical terms commonly used in the field.

You should remind your audience of definitions on the next several occasions after you introduce a new term or unit. But don’t needlessly introduce technical nomenclature that won’t be used again or that is superfluous because you can readily substitute more familiar language instead.

In a perfect world, you would always be happily disposed toward and fully engaged with your teaching and your students. In real life, touches of acting are important.

> You should appear confident, upbeat, and personable. You must make it appear as though you are in command of the subject matter (which won't always be true!) but not in a self-important way. You must appear well organized (there may not be a good way to fake this). You must appear eager to help your students understand; you do not want to seem condescending or pedantic. You must always seem interested in the material (tough after the 20th explanation of the phases of the Moon).

Be emphatic about important points. Because students rate the priority or value of a topic by your emotional temperature, being enthusiastic is important. If you don't seem interested in a topic, why should they be? However, you need to calibrate yourself. Excessive enthusiasm is wearing for the audience and physically tiring for you. It can appear silly and mindless, so be judicious.

Although almost all students appreciate some flash and glitz in classroom presentations, there are, of course, limits to how far you should go in this direction. Snappy performances don't necessarily motivate reluctant students; individual conferences might be better. Serious students can be put off by teachers who pander to low common denominators.

Unless you stand motionless and murmur (not recommended technique), you will discover that lecturing to a large class is physically demanding, even if you're in good condition. A 75-minute lecture can be equivalent to a one-mile run. You will find yourself getting tired and losing your edge. It's a good idea to have a sugar-loaded drink with you for a mid-lecture boost.

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**E. Public Speaking**

Your university probably offers optional training in public speaking (voice prep exercises, voice projection, and so forth), which can also address stage fright, shyness, student engagement, and similar issues.

Be conversational but with good organization. Deliberately modulate your voice. Avoid speaking for long periods in the same tone. Speak clearly, with enough volume to easily reach the back row. Depending on your normal speaking voice and shyness quotient, you may have to practice this and consciously track volume and clarity.

If a mike/amplifier system is available in a larger room, I strongly recommend that you always use it. People who think they can maintain the right volume throughout a long class rarely do so.

Pace your speaking. To be clear, you will have to speak more slowly and distinctly than normal, but you don't want to seem stilted.

Talk to the audience, not the projection screen, the chalkboard, your computer, or your notes.

No "uh’s" or "um’s" or other verbal tics! Think ahead and say it right the first time so there is little backtracking, rephrasing, or groping for words. (Rehearsals are enormously helpful in promoting smooth delivery and avoiding stumbles.) Use complete sentences with full stops.

Match your gestures to the importance of the point you are trying to make, but don’t be highly repetitive in gestures. Don’t fidgit.

Don’t stand in one place. Move around some, slowly, maybe across the whole front of the room. But don’t pace back and forth or make any other highly repetitive motions because these are annoying. Try to appear relaxed. If you use a lectern, don’t stay behind it for long periods.

Humor is greatly appreciated. If you aren’t likely to be spontaneously funny, then script jokes. There’s nothing shameful about that (needless to say, all professional comedians use scripts). Again, if you don’t have a natural comic streak, you’ll have to rehearse delivery.

You can critique your own performance using a video recorder.

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**F. Plots, Diagrams, Illustrations**

One of your important responsibilities in a nonmajors class is to carefully explain each figure you show or that students are expected to understand in the textbook.

Coming to grips with the implications of diagrams and images is an essential part of education in astronomy, but one for which students with inclinations toward humanities or social sciences may not be well prepared.

> Remember that some students have trouble understanding x-y plots and the mathematical concepts of functional dependence or correlation.
>
> Early in the semester, you may need to review the construction and implications of x-y plots. Plots with axes that run "backwards" or involve logarithms (e.g., color-magnitude diagrams) are particularly daunting. Even the concept of negative numbers on an axis needs review. A simple homework exercise in which students make such plots might be helpful.

Always take the time to introduce a new diagram. You may have seen it dozens of times, but your audience is seeing it for the first time. Explain axes, symbols, lines, and so forth before trying to convey meaning. Add clearer labels as appropriate (easy in PowerPoint). Explain the units and, if appropriate, remind the audience of conversions to more familiar units. Failure to explain diagrams is one of the most common shortcomings in presentations.

Textbooks now feature beautiful graphics. Unfortunately, many of the illustrations are egregiously distorted and not to scale. These feed misconceptions for students who don’t understand how to view them properly. They can be important barriers to student comprehension.

> For instance, it is easy for a student to misunderstand the ellipticity of Earth’s orbit (and its implications for the origin of the seasons) when looking at textbook figures shown from viewpoints other than a 90-degree inclination.

But the distortions and out-of-scale elements are usually not even mentioned in texts. The impression of the universe that a student would carry away from looking at only the illustrations in a typical text would be strange indeed. It’s up to you to apply corrective measures.

3-D geometry—especially the shapes of objects, orientation on a spherical surface, space motions, or the effect of perspective on appearance—is conceptually harder for many people than is arithmetic or algebra. This is one reason that they are slow to comprehend seemingly simple effects like the origin of the phases of the Moon or the seasons.

Even astronomical images can be confusing without a good explanation of perspective and scale.

Foreground stars are usually to be ignored, but you must explain that.

The 3-D structures of even nicely symmetrical systems like galaxies won’t be evident to a new audience, and those of complexes like the Orion or Eagle nebulae may baffle the most experienced viewers.

You must explain the angular sizes of objects on the sky and their relation to physical dimensions.

Remember that the colors in astronomical images are often not "true" and that very long integration times are often involved. Whether that is important to mention depends on the context.

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## G. Demonstrations

Demonstrations, no matter how elementary, are greatly appreciated and often very helpful to student comprehension because they make abstract ideas concrete. Unfortunately, it can be hard to find suitable demos for many topics. Departments commonly don’t offer good support for demo equipment, so this means that preparation, test, documentation, and repair are mostly up to you.

Plan on at least one hour of additional preparation time per lecture if you want to include serious demos (some may require rehearsal in the lecture room).

The best approach to engaging students with demonstrations is to ask them in advance what they think will happen.

Demonstrations can be very simple:

- An Earth globe and a light bulb to illustrate sunset/sunrise or the seasons. Add a piece of paper to illustrate the thickness of Earth’s biosphere.
- A scale model Solar System using an orange to represent the Sun (on which scale Alpha Centauri would be a second orange, 1,400 miles away).
- A nice visualization of cosmic timescales (courtesy of Francis Crick) is based on letting the length of the text in your textbook represent the age of the Earth and then asking how much time each letter represents. The answer will be several thousand years per letter. Ask your students to contemplate that while paging through the book.

- A good illustration of the area of the real sky can be given if you teach class during the day and can take your students outside. Try a "Sun-block" experiment where students measure the angular diameter of the Sun using their index fingers extended at arm’s length.

But, if it’s practical, make an effort to use more sophisticated equipment in demonstrations of the wave/particle nature of light, the function of optical systems, spectroscopy, electromagnetic phenomena, the Doppler effect, free-fall, impact cratering, and so forth. Show students binoculars, small telescopes, or spectrographs. Of course, you must set aside enough time to explain clearly what the students are seeing.

Show students real astronomical data sets (e.g., images from the digital sky survey databases or the HST archives, perhaps comparing unprocessed image frames to the final, glossy, full-color renditions), spectra, meteorites, catalogs, and so forth. It wouldn’t hurt to show them older photographic plates to emphasize how much data analysis in astronomy has been transformed in the last 25 years.

Software or Web-based (usually Java) demos/animations are now becoming widely available. These lack the "real-life" interest of a physical demo but are in principle able to illustrate concepts that are otherwise impossible to show and can be clearer and more effective than the real thing. However, be sure to vet these ahead of time; many have little value, and some are actually misleading.

Starry Night and similar commercial software packages provide a wide variety of nice planetarium-style demos but definitely require careful preparation. Irritatingly, the control and set-up formats seem to change with new editions, a serious impediment to classroom use.

Truly effective use of demonstrations, whether live or electronic, depends on having assistants available who can do the necessary design and preparation for which you don’t have the time.

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### H. Audience Interactions and Feedback

Listen critically to yourself while you talk. Try to put yourself in the place of students with little background in the subject. Watch for garbles, logical gaps, inconsistencies, unexplained terminology, forgotten illustrations, pacing problems, and so forth.

Look at individual students during your presentation. Get a sense from their body language whether they’re following, whether they’re bored. Paper "rustling" is a clue to distraction. A "hush" indicates interest (at least if there isn’t too much snoring). These days, students looking intently down often doesn’t indicate labored note-taking but instead an ongoing electronic conversation or Web surfing—watch for the cell phone glow.

Remember the 10-second rule: Wait 10 seconds after asking a question of the class before expecting hands to go up. Ten seconds is a long time in this context.

The 10-minute rule: Try to break up the presentation and the almost inevitable audience hypnosis at 10-minute intervals with pictures, videos, questions, demos, exercises, or simply a change of topic. Unfortunately, it is often hard to do this, especially when trying to complete coverage of something complicated.

A break or change of pace in the presentation is particularly important about halfway through the class.

Pauses are important. Learn how to stop talking and encourage questions from people who aren't getting it or have an interesting sidelight to pursue.

Always be respectful of questions and questioners. Some of the questions will be dumb. You should still answer carefully and seriously. Part of the job here is to keep the good students from laughing at the slower ones.

One way to identify places where your presentation needs revision is to ask students at the end of a class to list areas where they felt confused.

Be clear and honest about the limits of our current understanding and the things that we don't know.

A more delicate matter is how to answer questions where your own knowledge falls short—especially if the answer is sitting there grinning in the textbook. You don't want to let the students know that you have barely learned the material. There's no general rule, but give some thought as to how to handle such issues (e.g., by tossing questions to other students). If you can't answer now, make a point of answering in the next lecture. Students like to know that they have posed interesting or challenging questions.

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**I. Active Lecturing, Class Dialogue, Peer Instruction**

Information should flow both ways in the lecture hall. Work to make the classroom environment comfortable and open for your students and encourage an ongoing dialogue with them that will promote comprehension and engagement with the material.

From the first class, make it clear that you expect your students to be active participants.

A simple mechanism to improve interaction is to convert what might have been a straight declaration from you (e.g., a review of the last lecture) into a series of open questions for the class.

There are several well-studied special techniques to promote engagement with the material while simultaneously offering you valuable feedback even in very large lecture classes. You can find extensive discussions in Mazur (1997), Hake (1998), and Wieman & Perkins (2005).

The more popular techniques involve some form of "peer instruction," in which students collaborate on answering questions or solving problems. Working in pairs or groups helps the weaker students grasp the concepts but also helps the better students organize and articulate their understanding.. Students who have difficulty with abstractions are helped by confronting concrete examples. These are particularly effective in addressing the erroneous preconceptions harbored by students. Such exercises also tell students how well they are comprehending the key points.

Newly available wireless electronic "clicker" response devices can be very useful in this context (Wieman & Perkins 2005; Duncan 2006). They give you an instantaneous statistical summary of responses, from which you can decide where to elaborate or clarify your presentation. The best systems include software that automatically records individual student responses, which means that you can assign credit for participation and/or correct answers.

Of course, if the high-tech equipment isn't available, you can use paper forms (handwritten or Scantrons), ask students to write on the board, have them show "flash cards" indicating standard responses, or just ask for raised hands to obtain feedback.

A standard approach is to throw out multiple-choice questions to the class that either anticipate a conclusion that you have not yet reached in your presentation, ask for prediction of the outcome of a demonstration, or consolidate/test/review a concept that you have already described. Have students respond individually. Assess the answers. If too many people are having trouble, ask the students to collaborate on revised answers. Iterate, with additional explanation as required.

With sufficient planning, you can institute a form of "continuous evaluation" of your students' comprehension during lectures.

This kind of in-class engagement in moderate doses is widely recommended, and there are many different ways to configure it. But there are caveats:

You must plan ahead for the logistical and infrastructure requirements of in-class exercises; these can be nontrivial. Practice may be advisable. Consult others with more experience.

Inquiries must be well phrased and apropos. The exercises must be interesting and challenging to the good students as well as the weaker ones.

Without firm guidance from you, peer instruction can easily lead to misunderstanding the material.

You must learn how to gracefully corral the class after the exercises and refocus them on the lecture.

You must allow for the reduction in topic coverage that in-class activities incur. Decide whether to reduce the overall coverage of the course to compensate or simply to shift some material from lecture to home study or discussion sections.

The grading/recording burden of regular in-class exercises poses a dilemma. It is substantial if you lack electronic assistance, but without grades, students have less incentive to attend class or participate in the activities.

This approach works better if you require students to have read the textbook and class notes ahead of time.

Difficult concepts take a while to sink in. You may want to postpone an exercise to the meeting after that in which the corresponding material is presented and ask your students to review it in the meantime.

Because of the unconscionable prices charged by some manufacturers for clickers (over $50), it is advisable to initiate their use only if many disciplines in your school participate. Your administration must agree to adopt a single technology across departments. Malfunctions in the clickers can prevent students from receiving appropriate credit, a source of frustration for both them and you.

The software for the clickers (and other kinds of electronic teaching support) is not always compatible with Apple OS-X, now the most popular laptop system among astronomers.

Varieties of negative feedback: Some students, often good ones, object to the "grade-school" flavor of group exercises, find these tiresome or unproductive, or learn better on their own. The 30% or so of students who try to avoid coming to lecture classes will resent it if you award significant credit for in-class exercises. Some students like large lecture classes precisely because they are anonymous during them; you will be eliminating that advantage for them. For some fraction of your below-average students, peer interactions will only exacerbate frustration and unhappiness with your course.

Computer or Web-based exercises, with automated grading and grade recording, are another potential avenue for in-class engagement if you are in a well-equipped classroom with supplied computer workstations or a wireless system for student laptops.

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**J. Records**

Keep good written summaries of what you did in each class, how the students reacted, how to improve for next time. Otherwise you will quickly forget the details. Note conceptual snags, topics that inflated beyond expectations, areas for further explanation, needed new illustrations, ideas for new approaches, and so forth.

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# XVI. PROJECTED PRESENTATIONS

Astronomy is a visually spectacular subject, and nearly all teachers in elementary courses take advantage of that with frequent presentations of images to their classes. Most go beyond the pretty pictures to make projected text, images, and illustrations a staple of every class meeting. In many cases, there is good justification for using projected professional graphics rather than verbal explanations or crude drawings to explain astronomical concepts.

Until the start of this decade, the standard presentation media were viewgraphs and 35-mm slides. There has since been a nearly complete conversion to electronic projection, which now goes well beyond the traditional static presentations to include animations, videos, interactive demonstrations, hyperlinks, and other potentially powerful teaching media.

Students now tend to expect you to make regular use of good visuals. Take care, however, that you focus on those things that genuinely improve your students’ learning, and don’t allow emphasis on nice graphics to divert you from other, possibly more productive, aspects of teaching.

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### A. Effort and Resources

Preparation of good presentations for projection can be enormously time consuming. A set of digital notes in PowerPoint or HTML reflecting the contents of a single lecture, with illustrations and citations/links, can easily take five hours to put together. After all, besides writing the material, you are now assuming the obligation of publishing it as well. You will rarely be satisfied with the first version of a presentation and during subsequent offerings will probably invest at least twice as much effort in refining it. A mature set of digital notes for a single course usually reflects hundreds of hours of work.

Images and illustrations are much easier to incorporate electronically than in earlier teacher-created media. Large sets of beautiful astronomical images are now available on the Web. STScI, other NASA sites, NOAO, NRAO, and scores of independent compendium sites (e.g., Astronomy Picture of the Day at http://antwrp.gsfc.nasa.gov/apod/astropix.html) offer thousands of nice images. However, it is laborious to sort through all these and collect/organize the useful ones.

> You will often need to customize images. You can make simple adjustments (cropping, rescaling, contrast, resolution) using utilities like X-windows/xv, GIMP, Apple/Preview, PowerPoint, and so forth., without resorting to full-strength Photoshop. You can add labeling and other graphics using PowerPoint. Capture displayed images (e.g., from PDF or PPT files) using screen-shot utilities. JPEG is the most widely accepted image format at present.

Harder to come by on the Web are didactic illustrations (e.g., of stellar evolution in the CMD) that are simultaneously well-executed, clear, correct, and level-appropriate. Google Image Search makes it much easier to locate such items than it was just a couple of years ago, but you will find fewer than you hoped for. Many animations, ranging from simple animated GIFs or Java scripts to fully realized 3-D simulations, are also available on the Web.

> Even with the powerful software tools now available, it is very time consuming to make your own illustrations or animations: not recommended for people without tenure except for special cases.

Excellent graphics are now being distributed electronically by textbook publishers. These are extremely useful in presentations.

> Unfortunately, you must worry about copyright issues if you use material copyrighted by others either in class or on Web sites. You may not have continued legal access to publisher-generated media that you have been using for years if you change textbooks. The present unsettled state of copyrighting in electronic media is acting as an impediment to their use in teaching.

Materials to consider using go well beyond PPT or HTML files and include video or audio clips, Podcasts, animations, computer simulations, movies, and so forth. Despite the reputation of young people for having a video fixation, they don’t, in fact, always respond well to watching long videos (e.g., documentaries) in class.

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## B. Design

Projected material must be clear, easy to read, and streamlined. It takes care to properly condense and organize material for an effective presentation.

Basic content test for each page: Can an audience, unfamiliar with the subject being presented, comfortably read and absorb what is on the screen in the time it is shown while simultaneously listening to you and trying to understand what you are saying?

Use the smallest number of separate pages consistent with a clear and uncramped display.

Be sure that the text/annotations adequately explain any illustrations and that plots have complete legends. Keep in mind that your audience may not be adept in parsing diagrams and plots.

A good starting rule of thumb for projected presentations is that you should plan to discuss on average no more than one screenful of textual or diagrammatic material in five minutes. Over 50 minutes, you might be able to add another 10 slides of straightforward illustrative material that requires little explanation. You can accelerate the pace if it is clear that students are easily following you.

State-of-the-art digital projection can be beautiful. But you must be alert to adjusting color contrast, font size, embedded image size, and so forth. Test your projected material in the lecture room if there's any doubt; try viewing from several locations. Remember that not all your students will have good eyesight. Light text on a dark background using a sans serif font projects best.

Common flaws in presentations: low contrast between text and background; small fonts (e.g., on plot axes); small figures; too much information or wordy text; unexplained nomenclature/symbols.

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## C. Format

You have several choices. First, decide whether you will make your presentation files available to your students (e.g., by Web postings or CD-ROM). Then, think over the pros and cons before deciding on a file format.

Projected PowerPoint (PPT) files can look better than the alternatives and are widely used by astronomers for professional presentations.

> However, PPT has limitations in teaching, especially if you plan Web postings: The files are huge even for text-only pages (implying difficult transfer over slow data lines); can only be read or edited by proprietary Microsoft software; are slow to browse online (as is any slide-oriented format); are dilute when transferred to hardcopies; and only awkwardly integrate hyperlinks. Most research-oriented Unix/Linux computing systems do not support MS software (although Linux-based Apple OS-X does), meaning that you may not be able to use your primary desktop computer to develop presentations.
>
> There are significant compatibility problems with PPT. Files are not necessarily backward-compatible with older software versions, a serious difficulty if you intend to distribute them. Images manipulated within Apple PPT may not play properly on PC versions. The

expanding set of PPT-imitator software produces files that are usually mutually incompatible. You must check that your classroom equipment can handle your presentation files.

For these reasons, it is best to convert PPT files to PDF format for distribution. PDF is currently more widely readable and standardized, and it supports easier browsing and other handy utilities.

Although the nice animation effects in recent versions of PowerPoint can make live presentations more interesting and clearer, they will not transfer properly if you convert to other formats for posting or, obviously, to printable versions. Depending on the converter, they may actually obscure the content. This may force you to develop two versions of each presentation: one for the classroom and one for distribution.

By contrast, HTML files are compact, robust, system independent, and more widely readable (with any Web browser), and offer many more options to edit and iterate.

HTML files are fast to browse through on the Web and transfer relatively compactly to hard copies. Downloads of massive image files (stored externally to the HTML file) can be done selectively. Font sizes and colors are mostly adjustable to the reader's taste and eyesight. Hyperlinks to additional information are smoothly and reliably integrated and are useful in broadening coverage without forcing you to duplicate subsidiary information.

HTML accommodates an increasingly wide range of useful active scripting applications (e.g., Java) not present in PPT, lately including mechanisms for translating TeX-format mathematics.

The downside: HTML syntax can be annoying, fussy, and obtuse; you don't have access to the nice graphics and animations of PPT; and the ultimate display depends on the browser.

PDF files, created by any of several mechanisms (including TeX/LaTeX to PDF converters), are an alternative to PPT or HTML. These are usually intermediate in size, though like PPT, they lack smooth implementation of hyperlinks.

MS Word text files have size/compatibility difficulties similar to PowerPoint. The volume-to-content ratio (as measured by the sizes of the Word file and its equivalent ASCII content) can be 50:1. Avoid them.

PostScript files are needlessly large and don't allow the handy multi-utility access of the Adobe PDF format. Use PDF files instead. (Utilities like Unix/ps2pdf or Apple/Preview usually work well to convert PS files.)

The behavior of browser and other "print" utilities for converting presentations to hard copies varies widely, especially for grayscale printers. Check the quality of your students' hard copies.

Scandalously, mathematics remains awkward to integrate with either PowerPoint or HTML. If you want an easily editable, slide-oriented PDF alternative to PPT that fully accommodates mathematics, try the Prosper LaTeX package.

Whatever format you use, I recommend that you post class notes ahead of each class so that students can make hard copies to mark up during the in-class presentation.

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**D. Facilities**

Background light often interferes with projected images. Know when you must adjust room lighting for your audience to easily see what is on the screen.

> Turning room lights completely off prevents students from taking notes and also encourages them to sleep—both bad ideas. So, assuming the room is well designed such that the projection screen is shielded from note-taking lighting, keep some lights on unless you are projecting very dark images.

You should understand how to use the equipment. Know, for example, how to reset the brightness and contrast of the projector if they have been changed for some reason; how to cycle power on the projector; and how to test and reset I/O ports if you bring a laptop to class. Never assume an A/V system will work properly unless you have tested it beforehand in exactly the same configuration that you intend to use.

Beware the various single-point failures that will occur with computer-based lecturing. If there is an A/V failure, you have at most about five minutes to fix it. Then you must either continue without the electronics or send the students home. Know in advance which way you will go. The likelihood of a failure is high enough, unfortunately, that it is advisable to have a backup presentation at least mentally prepared.

Important accessories for smooth presentations include a well-designed podium with keyboard and monitor, a port for a laptop, high-speed Internet connections, good podium lighting for consulting notes, widely adjustable room lighting, blackout shades on windows, a clock for checking time, laser/hardware pointers, a good audio system, receiver units for electronic clickers, a large supply of appropriate batteries, good A/V documentation, and so forth. A wireless mouse gives you freedom to control your presentation from anywhere in the room, a great advantage if you are consulting with students during an exercise, for instance. Access to the lecture room at nonteaching hours is important if you need to rehearse or experiment with presentations.

One of the more irritating mannerisms enabled by new technology is the habit of mindlessly waving around a laser pointer. This is simultaneously confusing and distracting. The pointer is for pointing, not waving. Hold it still and on the thing you are trying to show the class; move it slowly to highlight related items. Then turn it off. Always check to be sure the pointer is easily visible from the back of the room. An invisible pointer is a classic source of audience frustration. The current generation of green lasers works better than red lasers.

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**E. Board Use**

Chalkboard/whiteboard use can seem more immediate and personalized than using projectors. By its nature, it will force you to emphasize the main issues, which is good. An advantage is that multiple layers of your presentation are simultaneously visible (depending on the size of the boards and how well organized you are in laying out material). But there are many drawbacks:

Board use is labor intensive during class, lends itself to frequent errors, is not good for any but the simplest illustrations, and can be hard for the audience to see.

People with bad handwriting or a lack of artistic aptitude should probably avoid regular use of the board (or practice more).

There is implicit pressure on students to take continual notes because there is no permanent record available of what you presented.

Board lecturing does not offer the opportunities to correct, polish, condense, or improve presentations that prepared digital material does. The time you invest in initial preparation of a digital presentation is partially repaid later by a reduction in review and planning time for subsequent offerings.

Some use of the board (e.g., for occasional illustrations) is, however, a good change of pace even with predominantly digital presentations.

"Starboard" electronic projection of handwritten material combines the strengths of traditional board presentations with modern technology (e.g., use of embedded digital images). You can also save the frames and post them later for your students.

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## XVII. THE WEB

Students now expect some kind of World Wide Web posting for each course. A class home page containing all relevant material (syllabus, schedule, lecture notes, announcements, grades, instructor contact information, links to recommended sites, and so forth) is very useful for all parties concerned and is strongly recommended.

It is best to post all special announcements regarding student assignments, deadlines, class activities, frequently asked questions, and so forth in a single file linked to your home page. Scrollable HTML formats are handy for this. Once students get used to referring to this posting, you will be significantly less pestered about such things. You can also create an archive of pertinent e-mail correspondence.

I strongly encourage you to post lecture summaries of some kind on the Web.

The easiest thing if you use HTML, PDF, or PowerPoint file projection in class is to post direct copies on the class Web page (see Sec. XVI concerning file types).

Alternatively, as a simple expedient, summarize each lecture in a few text paragraphs, with minimal illustrations but maybe with links to a glossary for technical terms.

At a minimum, post an outline.

Posted notes should emphasize your own approach to a subject and your priorities for student learning, so you shouldn't use unmodified publisher-supplied material.

In addition to posting Webnotes, you could post videos or Podcasts of your lectures. An alternative to Web posting is to distribute CD-ROMs of your presentations.

There is no question that posting detailed Webnotes encourages students to skip class. Studies show that absentee rates of up to 50% accompany Webnote postings in large lecture classes. Whether this compromises student learning hasn't been established.

The solution is not to forgo posting presentation summaries, but instead to provide some kind of "added value" for attending class. Greater engagement with students, particularly in clarifying difficult points, or assigning credit for in-class activities are among the better strategies here.

Various aspects of Webnote posting are controversial. Here are some with my opinions:

- Do Webnotes improve student learning and the classroom experience? (Yes, definitely.)
- Do students appreciate Webnotes? (Definitely, but not in direct proportion to your effort in creating them.)
- Should Webnotes be fully expository or condensed? (Condensed and streamlined.)
- Should they duplicate what you show in class? (Yes, this is important to give students confidence that they haven't missed anything.)
- One file or several per lecture? (One, so that everything comes up with a single mouse click. Length equivalent to no more than about five printed pages.)
- Is it better to post notes in advance of lecture? (Yes, and I encourage students to make hard copies to bring to class and mark up; a large fraction do this.)
- Should you post only outlines in advance of a lecture and complete notes only after? (This might promote closer attention during lectures, but it is more work for you and not optimum to support note taking.)
- Can Webnotes overwhelm students with too much material? (Yes, a major problem. Remember, they are already expected to read the textbook and must integrate the two media. Be selective in what you post, especially complicated diagrams, because students will believe that they are expected to understand that material fully.)

You can track student usage of your Web pages using the statistical analysis utilities implemented for most Web page servers. This gives you insight into their study habits that wouldn't otherwise be available.

A fundamental weakness of the Web as a teaching tool is that most Web sites are ephemeral, even if they are sponsored by otherwise stable institutions (e.g., NASA). The half-life of Web sites useful in teaching (or at least their addresses) is about two years. If you use links to other sites in your electronic materials, you must regularly check to see that the linked sites are still alive and useful.

Aside from simply hosting information, the Web opens up many opportunities for "second-generation" teaching tools such as discussion forums, interactive tutorials, data manipulation and display, collaborative exercises (including Wikis), online examinations, and so forth. These show great promise but have been slower to develop than might have been hoped. Most will involve more effort than superficially apparent, so the advice to new teachers is to be cautious and consult with others who have used them successfully before taking the plunge.

**The Value of Electronic Teaching**

> We have now had over 10 years of experience with widespread adoption of electronic teaching elements in science, including the Web. The record is mixed. I think that these have definitely enhanced teaching. Their main strength to date has been to offer students easy, 24-hour access to an astonishing variety of relevant material, including formats not readily available before (audio, video, animations), and to their instructors. In the right circumstances, this captures student interest and promotes engagement in ways that traditional textbooks cannot. Nascent second-generation teaching tools have great potential but are only now being widely adopted.
>
> However, electronic elements have certainly not reduced the human labor involved in teaching, as was the expectation of many early administrative enthusiasts. So far, the aggregate effort in electronic teaching has been added to, rather than substituted for, the effort prevailing in pre-electronic teaching. The cost-benefit ratio isn't well established yet, but it may well turn out to be higher than in pre-electronic teaching. Electronics are making teaching better, but someone has to pay for that improvement, as ever.

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# XVIII. INERTIA AND TEACHING REFORM

As a new and conscientious teacher, you will probably be eager to adopt the "best teaching practices" promulgated at the time. This makes good sense and costs nothing, since you are starting from scratch.

Five years later, your situation will have changed. You will have achieved a pragmatic equilibrium between time devoted to classroom teaching and your other obligations. You will have invested heavy start-up effort to make perhaps three to five courses run smoothly. Your teaching files will be approaching 10 cubic feet, or the equivalent electronic space. You will be looking forward to amortizing all your initial effort over a number of similar offerings of each course. In short, you will have acquired "teaching inertia."

At that point, you will find yourself much less receptive to campaigns for reform in teaching. You will suddenly understand why professors who had generated a three-inch-thick stack of carefully refined, handwritten viewgraphs for each course reacted badly to the breezy suggestion to dump them and switch to PowerPoint. Ironically, inertia is an almost inevitable by-product of a commitment to good teaching.

Calls for teaching reform come from two main sources: your university administration and external educational researchers. Most of these are well intentioned and are based on some kind of evidence concerning the actual effectiveness of different teaching practices.

You should realize that what "reform" almost always means is more teaching hours from faculty—that is, you. University administrators and critics often deliberately intend this because it is an article of faith among them that faculty are underemployed (it's that "three-hour" thing). Reforms proposed by administrators and critics rarely involve larger budgets or more personnel to help you teach.

Other reformers may not intend for you to spend more time, but they often don't properly assess the necessary new effort in the context of what you already do. They don't tell you what to forgo doing in order to implement their reforms. "Opportunity cost" is only rarely part of teaching reform discussions.

In this situation, your response should always be to insist on a hard-nosed cost-benefit analysis, preferably based on pilot programs. The burden is on the reformers to make their case.

You should insist that the extra time necessary to implement the reforms, assuming they look promising, comes from the time you already invest in teaching and that the net change in effectiveness of shifting that effort is likely to be positive. In other words, acceptable reforms should increase the *efficiency*, not the quantity, of your teaching effort.

**The Web and Teaching Reform**

> The Web is transforming teaching. One of the Web's key contributions is that it gives you instant access to thousands of online courses and supporting material from around the world. This open exchange of teaching information is fundamentally new in higher education. Traditionally, only a small percentage of faculty ever concerned themselves with global teaching improvement, and they exchanged ideas in a small arena that was effectively invisible to most frontline teachers. There was no open, heavily subscribed, readily accessible forum where ideas confronted one another. (This is unlike the situation in research and may explain why progress in science education since the Sputnik shock has lagged behind progress in scientific research.) The Web is now changing this. As long as universities resist the pressure to hide their teaching materials behind proprietary firewalls, the Web will promote real improvements in teaching.

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