

GOALS FOR “ASTRO 101”: A REPORT ON WORKSHOPS FOR DEPARTMENT LEADERS

by

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I. GOALS FOR “ASTRO 101”:REPORT ON WORKSHOPS FOR DEPARTMENT LEADERS

ABSTRACT

Roughly 10 percent of all US college students take an introductory astronomy course while in college. The vast majority of these are not science majors, and this course often represents the only college-level science these undergraduates will ever encounter. The challenges posed by these courses were recently discussed at two workshops for chairs and other department leaders from selected research universities. Here we report on a set of goals for such courses formulated by the participants, and list some strategies to help accomplish them. Section I of the report provides a brief summary and list of the goals endorsed by all participants at the two meetings. Section II is a longer report on the meetings and a detailed list of goals and strategies prepared by two participants.

SUMMARY

1.A THE NEED FOR GOALS FOR ASTRONOMY 101

Each year, astronomers are involved in teaching introductory astronomy courses (which we will call “Astro 101”) to over 250,000 undergraduates¹ in the US and Canada. The vast majority of these are not science majors, and this course often represents the only college-level science these undergraduates will ever encounter. Astronomy, because of its broad appeal and the wide-ranging issues it addresses, is an ideal vehicle for exposing such students to science. Its well-established links with other fields such as physics and geology make astronomy intrinsically interdisciplinary, so that Astro 101 also serves the function of introducing these students, however briefly, to these disciplines. Pre-service K-12 science teachers often enroll in Astro 101, ensuring that any systemic improvements in the course will be effectively leveraged. Astro 101 thus offers a valuable opportunity to meet some of the education goals laid out for the astronomical community in the most recent Decadal Survey, *Astronomy and Astrophysics in the New Millennium* (2001).

Our community, however, has not established, or even widely discussed, goals for such courses. Rather, since “Astro 101” is so widespread, it is assumed that everyone will teach it in his or her own way. Indeed, we often teach in just the way we experienced our own education. This represents a sadly missed opportunity, for in recent years many exciting new pedagogical strategies and resources have been developed. Studies of introductory courses in related disciplines (e.g., physics: see Laws, 1997; Redish and Steinberg, 1999; Crouch and Mazur, 2001; see also the useful Web site www.wcer.wisc.edu/nise/cl1) have identified a number of strategies which increase student learning in the standard, large-lecture format used in most Astro 101 classes. These strategies pertain both to textbooks and to course syllabi, both of which traditionally tend to emphasize complete coverage rather than deep understanding. Given both the large enrollments in Astro 101 and the emergence of educational scholarship that could

¹ Demographics are briefly addressed in Appendix A.

influence and improve such courses, a reexamination of the goals of Astro 101 seemed warranted.

I.B AAS RESPONSE

In response to this need, the Education Office of the American Astronomical Society instituted a two-pronged approach to examining, reforming and improving Astro 101.

- *Assistance to those actually teaching Astro 101.* Ongoing workshops are being held in which new astronomy faculty members are exposed to new pedagogical strategies and resources. These workshops are run jointly with the American Association of Physics Teachers and the American Physical Society, and supported by an NSF grant. In addition, at each AAS meeting, the AAS Education Office sponsors a day-long or half-day meeting focused on Astro 101. We have also joined with the Astronomical Society of the Pacific to sponsor the biennial “Cosmos in the Classroom” meetings which reach many Astro 101 instructors in community colleges as well as those in universities
- *Workshops for Department Leaders.* Two workshops on the goals of Astro 101 were held for chairs and other department leaders from selected major research universities. The workshops involved three dozen participants from 30 institutions (listed below). They were supported by NSF grant DUE-9952353, and hosted by the University of California, Berkeley, and the Center for Astrophysics at Harvard.

We report here on the findings of these two national meetings.

The goals of the workshops for department leaders were: to foster conversations among the participants on the difficulties encountered and the strategies they employed in mounting their departments’ Astro 101 offerings, to expose them to a series of reports from education experts, and to ask the participants to formulate sets of recommended *goals* and a longer list of useful *strategies* for such courses for later review by and dissemination to the wider astronomical community.

I.C GOALS FOR ASTRO 101

Why do we teach introductory astronomy to non-science majors, and what do we want our students to take away with them at the end of the semester? After considerable discussion, the workshop participants attempted to formulate responses to these questions in the form of a set of recommended goals for Astro 101. Remarkably, the goals adopted by the two workshops turned out to be quite similar. (This was in spite of the fact that participants in the second workshop did not see the goals proposed by the first until after they had adopted their own.) The following are the agreed-upon goals for Astro 101:--

GOALS (CONTENT)

Students should gain:

- a cosmic perspective--a broad understanding of the nature, scope and evolution of the Universe, and where the Earth and Solar System fit in
- an understanding of a limited number of crucial astronomical quantities, together with some knowledge of appropriate physical laws

- the notion that physical laws and processes are universal
- the notion that the world is knowable, and that we are coming to know it through observations, experiments and theory (the nature of progress in science)
- exposure to the types, roles and degrees of uncertainty in science
- an understanding of the evolution of physical systems
- some knowledge of related subjects (e.g., gravity and spectra from physics) and a set of useful “tools” from related subjects such as mathematics
- an acquaintance with the history of astronomy and the evolution of scientific ideas (science as a cultural process)
- familiarity with the night sky and how its appearance changes with time and position on Earth.

GOALS (SKILLS, VALUES AND ATTITUDES)

1) *Students should be exposed to:*

- the excitement of actually doing science
- the evolution of scientific ideas (science as a cultural process).

2) *Students should be introduced to how science progresses, and receive training in:*

- the roles of observations, experiments, theory and models
- analyzing evidence and hypotheses
- critical thinking (including appropriate skepticism)
- hypothesis testing (experimental design and following the implications of a model)
- quantitative reasoning (and the ability to make reasonable estimates)
- the role of uncertainty and error in science
- how to make and use spatial/geometrical models.

3) *And we should leave students*

- more confident of their own critical faculties
- inspired about science in general and astronomy in particular
- interested in, and better equipped to follow, scientific arguments in the media.

These goals are explained more fully in the body of this report (section II), where illustrative examples are given for many.

We are struck by what the participants did *not* do: they made no attempt to design a curriculum, or to propose a detailed set of standards for Astro 101. Rather, the content goals they adopted are very general, and emphasize student development more than astronomical content. The goals also reflect the view that “less is more.”

I.D IMPLICATIONS

The set of goals adopted by the workshops carry broad implications for how we teach our Astro 101 students:

- The participants rejected the notion of an irreducible core of essential knowledge, to which every Astro 101 student should be exposed.
- “Less is more:” Participants rejected the notion that Astro 101 ought to survey the entire field of astronomy.
- Many of the goals refer to broad aspects of the scientific enterprise. A goal such as “students should understand that physical laws and processes are universal” was deemed more important for Astro 101 courses than “an understanding of the HR diagram” for instance.
- Many of the goals go far beyond what is customarily taught in such courses. How, for instance, are we to teach “that physical laws and processes are universal”?
- The goals require us to alter our techniques of assessing our students. If our homework sets and exams continue to cover only factual material, students will understand full well where their efforts should go.

These are not problems the workshops solved. The workshop participants recognized that the set of goals they adopted poses a substantial challenge to the entire community of astronomers. It will take much debate to formulate how to respond appropriately to the new view of Astro 101 embodied in these goals.

Some strategies and approaches for implementing these goals are laid out in section II.D of the longer report that follows this summary. Unlike the case for the goals, no consensus was reached on any particular strategy, nor was any particular priority assigned to them. The suggestions by department leaders, however, may be useful to both individuals and departments seeking to reform Astro 101.

This Summary Endorsed by All Participants:--

Jon Arons , University of California, Berkeley
 Bruce Balick , University of Washington
 Tom Brown, Montana State University
 Gerald Cecil, University of North Carolina
 You-Hua Chu, University of Illinois

Grace Deming, University of Maryland
Doug Duncan, University of Chicago
Dick Durisen, Indiana University
Alex Filippenko, University of California, Berkeley
Tom Fleming, University of Arizona
Andrew Fraknoi, Foothill College
George Greenstein, Amherst College
Richard Henry, Johns Hopkins University
John Kielkopf, University of Louisville
Len Kuhi, University of Minnesota
Karen Leighly, University of Oklahoma
Alan Marscher, Boston University
Bob Mathieu, University of Wisconsin
Eric Mazur, Harvard University
Dick McCray, University of Colorado
Edward Murphy, University of Virginia
Gerald Newsom, Ohio State University
Stacy Palen, University of Washington
Bruce Partridge, Haverford College
Liane Pedersen-Gallegos, University of Colorado
Vahé Petrosian, Stanford University
Joe Redish, University of Maryland
Bob Rood, University of Virginia
Dimitar Sasselov, Harvard Smithsonian Center for Astrophysics
Steve Schneider, University of Massachusetts
Elaine Seymour, University of Colorado
Irwin Shapiro, Harvard Smithsonian Center for Astrophysics
Steve Shawl, University of Kansas
Ron Snell, University of Massachusetts
Sumner Starrfield, Arizona State University
Steve Stonebraker, Boston University
John Thorstensen, Dartmouth College
Sheila Tobias, author/consultant
John Trasco, University of Maryland
David Tytler, University of California, San Diego
Jacqueline Van Gorkom, Columbia University
Gareth Wynn-Williams, University of Hawaii

II. A REPORT ON TWO NATIONAL MEETINGS ON THE GOALS OF “ASTRO 101”

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II.A THE NATIONAL CONTEXT

“The United States today has the finest scientists in the world and the worst science education in the world, or at least in the industrialized world.” David Goodstein

A variety of studies have suggested that the educational system in the United States is missing many opportunities to serve the nation’s students well. Concerns about the quality of our educational system certainly extend to science education, as pointed out, for instance, by studies such as *A Nation at Risk* (www.ed.gov/pubs/NatAtRisk/index), and studies of student performance such as the *Third International Mathematics and Science Study*. While much of the concern and many of the corrective actions have focused on precollege (K-12) education, there is also abundant evidence that science courses in our colleges and universities could do a better job of preparing both professional scientists and scientifically literate members of the public. The evidence comes in many forms, from studies in related disciplines such as those by Laws (1997), Redish and Steinberg (1999) and Crouch and Mazur (2001); to national studies such as *Shaping the Future* from the National Science Foundation (George *et al.*, 1996) and *From Analysis to Action* from the National Academy of Sciences (Kennedy *et al.* 1996); and to our own experiences in the classroom.

We would also suggest that the dwindling number of physical science majors in the US is linked to problems in our undergraduate courses. In the case of physics, the number of physics Bachelor’s degrees produced in the years 1999 and 2000 was about at pre-Sputnik levels. The number of doctoral students in the physical science has stayed more stable, but it is well known that the number of US citizens entering physics graduate study is dropping rapidly. At a finer level of detail, all of the decrease in the number of physics majors has occurred in Ph.D. and Master’s-granting institutions; the number of physics students produced by Bachelor’s-granting institutions has stayed essentially stable since 1965, and now equals the production of physics Bachelor’s degrees from Ph.D.-granting institutions. While the number of Bachelor’s degrees in astronomy is small enough to be subject to larger fluctuations, the number has hovered around 180 per year since 1978, with some indication of a slight increase in the last 10-15 yrs. While changes in the number of science *majors* may at first appear unrelated to the question of how we teach Astro 101, we would suggest that majors and non-majors alike can be discouraged by poor pedagogical techniques. As shown by Seymour and Hewitt in *Talking about Leaving* (1997), high-performing students are just as likely to be turned off by our present teaching practices as other students are. These data, while fragmentary in the specific case of Astro 101, point to the general need for reform of our undergraduate programs.

Perhaps it is no surprise that non-science students find science intimidating. But it *is* surprising that they find it dull—a mere collection of facts to be memorized. We need to recapture our students’ interest and goodwill. We should also aim for student learning and attitudes that *last*—not just until the final exam, but for the rest of our students’ lives as informed citizens. This too would be a service to our students, and to our nation.

Funding agencies make this point frequently. Both the NSF and NASA are doing more than raising concerns and demonstrating deficiencies; they are also actively supporting systemic reform in undergraduate science education, with the NSF leading the way.

Means to improve undergraduate science education have been explored by our colleagues in several other disciplines. Physicists are engaged in a number of projects to improve undergraduate physics education, for instance: (1) there is a Task Force examining general reform of undergraduate programs (www.aapt.org/programs/ntfup/index.html) and (2) the Physics Teacher Education Coalition is reviewing introductory physics courses taken by pre-service teachers (www.phystec.org). Our colleagues in chemistry have historically been quite prescriptive about the undergraduate curriculum in their field. The American Chemical Society has more recently developed course materials for non-science majors as well (see <http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education\professional\index.html>). Geophysicists are also looking at curricular reform (see http://serc.carleton.edu/NAGT_workshops/), as are colleagues in mathematics.

These approaches are generally firmly based on research findings on how students learn (and why they fail to). Research findings in science pedagogy are increasingly informing teaching practices in astronomy as well. In astronomy, as in related disciplines like physics, we are developing a cadre of experts in science education research. In the last year, an electronic journal, *Astronomy Education Research* (<http://aer.noao.edu>), has been launched, several institutions have appointed experts in science education to their astronomy faculties, and the American Astronomical Society has endorsed research in astronomy education (see www.aas.org/education/).

Astronomy differs from its sister disciplines like physics and chemistry in that the bulk of our undergraduate teaching focuses on non-majors. Each year, astronomers teach introductory astronomy courses (which we will refer to as “Astro 101,” whether or not they are generic survey courses) to more than 250,000 undergraduates in the US and Canada*. (While this report focuses primarily on undergraduate education in the US, many of our findings have direct applicability to Canada, where the educational system parallels reasonably closely that in the US. We recognize that our findings are less likely to be applicable in countries where science education for non-science undergraduates is less emphasized.) Since US institutions produce only about 180 astronomy majors per year, the vast majority of the students in our introductory courses are not science majors, and for a large number of them, Astro 101 represents the only college-level science course they will encounter. Just because of its broad appeal, astronomy is a popular subject for study. Statistics compiled by the AIP suggest that Astro 101 annually enrolls as many or more non-science students than introductory courses for non-majors in any other discipline. We would also claim that astronomy, because of its deep links to related fields, has the potential to serve as an ideal way of introducing students to science in general and to the scientific method.

For all these reasons, both the astronomical community and its professional societies such as the American Astronomical Society (AAS) and the Astronomical Society of the Pacific (ASP) have focused attention on the reform of Astro 101.

* Demographics are considered in Appendix A.

Every 2-3 years, the ASP, with support from the AAS, has held a meeting devoted to Astro 101 and good teaching practices aimed primarily, but not exclusively, at teachers in community colleges. This is “Cosmos in the Classroom,” next scheduled for July 2004. The AAS has adopted a 2-pronged approach to support professors teaching Astro 101 and to promote reform in such courses.

- (1) The AAS offers assistance to those currently teaching Astro 101, including a one day “how-to” session at each AAS meeting called “Astronomy 101: A Continuing Dialogue.” In addition, every AAS session now includes oral and poster sessions touching on Astro 101, associated laboratory or observational work, new astronomy-related Web sites, and so on. Finally, in concert with the American Association of Physics Teachers (AAPT) and American Physical Society (APS), the AAS sponsors longer workshops for new astronomy and physics faculty to expose them to new pedagogical strategies and resources as well as to promote networking among faculty just starting their teaching and research careers.
- (2) The second approach taken by the AAS to stimulate change in Astro 101 was a pair of small and intense workshops held for department chairs to assess and refine the goals for such courses. This section is an analysis by two of the participants of these two meetings, held in the late spring and summer of 2001.

II.B TWO NATIONAL MEETINGS ON GOALS FOR ASTRONOMY 101

An important part of the AAS strategy to promote systematic change in Astro 101 is to enlist the support of department chairs and other department leaders in such reforms. Junior faculty (or others serving in the 101 classroom) are not in a position to reform Astro 101 on their own. If such courses are to be improved, both money and release time must be allocated appropriately. Such allocations are departmental decisions, not individual faculty members'. Successful and lasting systemic change also requires a culture within astronomy departments which encourages educational activities, and rewards them. The support and encouragement of department chairs or other leaders is crucial to the enterprise.

With these aims in mind, the AAS sponsored two national meetings in the spring and summer of 2001 for department chairs and other leaders to examine the goals of the set of introductory courses for non-majors we call here “Astronomy 101.” Those invited to attend were astronomy department or program chairs or other senior scientists at major research universities. Our rationale for this (initial) focus on research universities was that if any departments play a leadership role in the astronomical community, it is these. If their teaching practices are systematically reviewed and improved, it is more likely that those in 2 and 4-year colleges will follow suit than the reverse. Furthermore, writers and publishers of textbooks are more likely to pay attention to systemic reforms in large and influential institutions than developments in smaller institutions.

Proposal to NSF/EHR

In the spring of 2000, four persons associated with the Astronomy Education Board of the AAS drew up a proposal to the Division of Undergraduate Education of the NSF Directorate of Education and Human Resources. These were Gina Brissenden, Douglas Duncan, George Greenstein and Bruce Partridge (PI). We proposed two small but intense national meetings of department leaders, one on each coast. We also proposed a pre-meeting survey questionnaire to gather demographic information and to prepare participants for the meetings. We included plans

for extensive evaluation of the meetings during and after them, and follow-up both to refine the recommendations of the meetings and to disseminate them widely. To expose department leaders to new pedagogical techniques, astronomy or science education experts were invited to each meeting to present and model novel teaching techniques. The NSF kindly agreed to fund these sessions; some matching funds were provided by the AAS.

Structure of the Meetings

Invitations were sent to the department chairs of approximately 60 large astronomy departments or programs. For the reasons mentioned above, we elected to focus on large research universities, and restricted our invitation to US institutions. Our proposal specifically mentioned future hopes and plans of the AAS to join with the ASP to extend discussions of the goals of Astronomy 101 to a wider set of institutions. Each of the 60 departments was invited to send a department chair or other leader with a direct link to the department's introductory astronomy courses. We also asked departments to consider sending 2-person teams, consisting of a department chair and an experienced Astro 101 teacher, and several did.

The invitations to departments were preceded by a letter signed by 18 senior and distinguished astronomers, including past, present and future AAS Presidents, urging departments to give the invitation careful consideration and support.

Of the institutions invited, roughly 1/4 never responded, despite follow-up e-mail or letters. In the end, faculty members from 30 institutions attended one or another of the meetings, sometimes in two person teams.

Early in the grant period, we developed a questionnaire, which was then distributed to the participants before the meeting. The purpose was to assemble data on demographics relating to Astro 101 students (their actual or planned majors, science and math background, gender, etc.); demographics relating to the classroom environment, including class size and the availability of information technology; and information on departmental resources allocated to teaching introductory courses for nonmajors. This pre-meeting survey appears in Appendix B along with a summary of the responses.

We also asked the participants to discuss with other members of their departments the current departmental goals for Astro 101. The findings of these discussions, as well as the results of the pre-meeting survey, provided an initial focus for the meetings themselves.

The Astronomy Department of the University of California, Berkeley, agreed to host one of the meetings, held in May 2001; the other was held at the Center for Astrophysics at Harvard in June. The organizers are deeply grateful to the substantial support of both institutions.

The agendas of the two 1.5 day meetings were drawn up in consultation with the participants; in the end the two agendas were closely the same. Each meeting began with a review of the results of the pre-meeting survey and the list of issues arising from departmental discussions. Then the participants heard from education research experts on problems with the current approach to courses like 101, followed by reports on innovations that work. A list of the education experts and other speakers appears in Table 1, along with a brief description of the role each played at the meeting; see Appendix C for details.

These presentations were followed, by design, with ample time for the participants to talk among themselves and with the experts. Some of these discussions were topical (e.g., what is the role of labs and/or computer labs in 101?); some were open and free-wheeling.

Each of the two groups of department leaders then drew up a *list of goals* for introductory courses for non-majors. While these two lists of goals were arrived at independently (the list from Berkeley was not revealed to the participants at Harvard until the end of the meeting), the two lists of goals were remarkably similar. The final list of goals is presented fully in section II.C.

Each meeting also produced a long list of recommendations for the implementation of these goals. These ranged from suggestions to departments and individual Astro 101 teachers to recommendations to professional societies and funding agencies. Not all of these recommendations were fully discussed at both meetings. In addition, the lists of recommended strategies from the two meetings were quite different. In section II.D, we present the union of these two sets of recommendations, ordered after the fact by us, with some comments on many of them.

<i>Role of “Experts”</i>	<i>at Berkeley</i>	<i>at Harvard</i>
Host (and “wise astronomer” interested in education)	Jon Arons	Irwin Shapiro
Asked if courses like “Astro 101” do meet science education goals	Robert Mathieu (Univ. of Wisconsin)	Elaine Seymour (Univ. of Colorado)
Presented curricular innovations that work	Joe Redish (Univ. of Maryland)	1. Dick McCray Liane Pedersen-Gallegos (Univ. of Colorado) 2. Eric Mazur (Harvard)
Suggested ways to make lasting systemic changes	Sheila Tobias (consultant)	Sheila Tobias
Discussion leaders, minute takers	Andrew Fraknoi (Foothill College) Bruce Partridge (Haverford College)	George Greenstein (Amherst College) Bruce Partridge
Evaluator	Tom Brown (Montana State)	Tom Brown

Table 1. Experts and commentators, and the roles they played.

In the case of the *goals*, these are the consensus recommendations to the astronomical community by all the participants. The implementation *strategies*, on the other hand, are merely suggestions that departments, those teaching Astro 101 and others may wish to discuss or consider.

Follow-up after the National Meetings

Immediately after the two national meetings, the lists of goals developed at the meetings were merged and ordered. The material that forms part I of this report was drafted. The draft of part I, including the list of goals, was submitted to all participants at the two meetings with a request for comments and revisions. Once those had been included, all participants at the two national meetings endorsed the list of goals and the remainder of part I of this report.

In parallel with this effort, the list of goals was also brought to a dedicated session at the AAS Meeting held in January of 2002. Further refinements and suggestions emerging from that meeting have been included in this report. (See Bulletin AAS **33**, 1414.) Additional sessions to publicize the goals and strategies devised at the national meetings were held at subsequent AAS meetings in June, 2002 and January, 2003.

We also included three forms of evaluation in the proposal submitted to the National Science Foundation. An outside evaluator, Tom Brown of Montana State University, attended both meetings in full, and provided the organizers with real time, formative assessment. He also carried out a summative assessment based on interviews with some participants. These interviews were conducted during the winter, 2001-2. Summaries of both evaluations are included here in Appendix D. Finally, we plan a follow-up survey of all participants in the summer of 2003 with the aim of determining whether or not the discussions held at the two national meetings have resulted in changes and/or improvements in the way astronomy is taught to nonmajors at the participants' institutions. Conducting such a survey just 2 years after the meetings may be a bit early, but we promised the NSF we would do so, and we do plan further follow-up, perhaps 5 years after the meetings were held.

II.C GOALS FOR ASTRO 101

We are struck by what the participants in these two meetings did *not* do: they made no attempt to design a curriculum, or to propose a detailed set of *standards* for Astro 101. Rather, the content goals they adopted are very general. As opposed to urging us all to teach Kepler's Laws or stellar classification, they called for "an understanding of a limited number of crucial astronomical quantities." Furthermore, they made no attempt to define what these quantities should be. Rather, their sense was that every instructor was free to define this for him- or herself. Indeed, both workshops rejected the notion of an irreducible core of essential knowledge, to which every Astro 101 student should be exposed. This is in interesting contrast to findings by Brissenden *et al.* (1999) who polled current Astro 101 instructors on their goals and listed responses ranging from "an appreciation of the size scale and structure of the cosmos" to "the stellar magnitude scale" as key learning goals.

Associated with broad focus was a sense on the part of department leaders that "less is more." Participants rejected the notion that Astro 101 must survey the entire field of astronomy. Indeed, they felt that tightly focussed courses ("The Search for Extraterrestrial Life" or "The Expanding Universe") might prove as educational--and more interesting, both to the students and to the instructor--than the traditional survey course. If the general notion of a survey is retained, participants felt that instructors should focus on a limited number of important themes in astronomy, such as the evolution of physical systems or "how we know what we know."

A third important issue is that many of the goals adopted were quite general, and referred to broad aspects of the scientific enterprise. While astronomy majors might need to understand

the HR diagram or the CNO cycle, a goal such as “students should understand that physical laws and processes are universal” was deemed more important for Astro 101 courses. Similarly, many of the adopted goals concern skills and attitudes rather than content: participants called for “training in critical thinking, including appropriate skepticism,” for instance.

Many of the goals go far beyond what is customarily taught in such courses. How, for instance, are we to teach “that physical laws and processes are universal?” We are all used to teaching the latest observational data on Mars – but we are not used to teaching why we trust that $F=ma$ is just as valid on Mars as it is on Earth. While we know how to teach about the expanding universe, how would we go about teaching “that the world is knowable?”

Other goals address our students’ skills, values and attitudes. Here too, the workshop participants are asking us to alter our traditional modes of instruction. Do our current Astro 101 courses give our students “training in critical thinking, including appropriate skepticism,” or in “the analysis of evidence and hypotheses”? If they do not, shouldn’t they in the 21st century?

Similar comments apply to the textbooks we write and adopt. Most workshop participants were united in decrying the tendency of textbooks to cover every imaginable topic. Participants were also united, however, in understanding the reasons for this tendency. Only when we as teachers cease demanding that textbooks cover every one of our own favorite topics will textbooks start shrinking and focusing.

Finally, these goals require us to alter our techniques of assessing our students. Students are very good at “reading our actions,” and seeing through what might be empty pieties. No matter how we revise our courses and reorder our goals, if our homework sets and exams continue to cover only factual material, students will understand full well where their efforts should go. There is a crying need for tests and other assessment methods that “get at” deep understanding, not quickly learned and quickly forgotten facts.

Some of the goals listed below would surely be accepted by anyone teaching Astro 101 or a similar course (though whether the course would fully address the goals is another question). On the other hand, other goals recommended in these workshops may seem either less obvious or much harder to meet. To meet such concerns, we list the goals again in this section, and provide an explanation or justification for each and/or provide some illustrative examples of how the goal might be incorporated in an Astro 101 course. Many of these examples or explanations emerged during the two national meetings, but there was no attempt to reach consensus on them; and some were devised after the meetings by the two present authors or others.

GOALS (CONTENT)

Students should gain:

1.) *A cosmic perspective--a broad understanding of the nature, scope and evolution of the Universe, and where the Earth and Solar System fit in.*

Surely this is the kind of understanding we hope our students will grasp, appreciate and retain. An understanding of the immensity of the Universe, and of its great age (and how we know both), is both more important and more likely to remain with our graduates than a fact like the distance to M31. We would add that an appropriate cosmic perspective may be particularly beneficial at a time when state Boards of Education are susceptible to Creationist or “Intelligent Design” alternatives to modern science.

- 2.) An understanding of a limited number of crucial astronomical quantities, together with some knowledge of physical laws.

The notion is to focus on basic, general phenomena and laws, very much in the philosophy of “less is more.” This is not a recommendation to make Astro 101 “fact-free.” Students should learn basic quantities like the Astronomical Unit as a measure of scale in the solar system, parsecs (or light years) as a measure of interstellar distances, and some appreciation for intergalactic distances, for instance, as well as basic phenomena like gravity. Basic quantities like a solar mass and a solar luminosity should be taught, as well as basic physical properties of main sequence stars. On the other hand, is it necessary for students to understand the magnitude scale or spectral classification? Isn’t the actual chemical composition of stars (and its uniformity) more important than its manifestation in stellar spectra? Astronomy majors may need to understand the curve of growth; but do future lawyers or doctors?

- 3.) *The notion that physical laws and processes are universal.*

The triumph of Newtonian gravity in the discovery of Neptune is an excellent and illustrative example—gravity does work even at the edge of the solar system. The use of Newtonian physics to infer the existence of dark matter (rotation curves of galaxies) is another. Our ability to determine the chemical composition of objects millions or billions of light years away, using spectroscopy, is a third. These are all examples of the extension of physical laws and methods to astronomical systems. More subtly, there are cases like the discovery of He in which astronomical discoveries inform and enrich physics or chemistry.

- 4.) *The notion that the world is knowable, and that we are coming to know it through observations, experiments and theory (the nature of progress in science).*

Here, the aim is to demystify science. One could imagine discussing not just the facts of science, but the process whereby scientists come to accept them. What do scientists mean by “theory.” How are theories tested and refined? What is the role of observation in astronomy? Ideally, courses themselves should reflect proper scientific method, by emphasizing observations and drawing conclusions from them. The aim is to differentiate science from a belief system—this would be an excellent opening to discuss astrology—and to illustrate the methods by which our understanding of the world is both achieved and continually tested.

- 5.) *Exposure as to the types, roles and degrees of uncertainty in science.*

We discussed this point briefly in the introductory remarks above. The intention is not to teach statistics, or even what a standard deviation means. Rather it is to get students to think about the uncertainty in any measurement and the consequences of that uncertainty. This applies to both students’ own measurements (in labs, for instance), and in measurements we scientists make (with Hubble’s constant a useful example). We need to be careful on this point because most textbooks give measurements without error bars (e.g., look up the mass of Mars in the textbook you are using). Students will appreciate error analysis only if we can motivate its importance. Here Kepler’s introduction of the notion of elliptical rather than circular orbits can be relevant: this advance in our understanding was only possible *because* Brahe knew his observational error to be less than the tiny anomaly in the orbit of Mars. Similarly, Newtonian gravity was supplanted by General Relativity in part because of GR’s success in accounting for the precession of the perihelion of Mercury: here too, an advance was possible only because the

accuracy of both observation and theoretical calculation was known. There is every reason to explore these uncertainties and their consequences with students.

6.) *An understanding of the evolution of physical systems.*

The notion that physical systems—be they stars or planetary surfaces—change in time is not directly apparent in astronomy, because in most cases the time scales are very long. Nevertheless, there are some beautiful examples in our field of the gradual evolution of systems operating under physical laws. We two believe that this is one of the “great stories” of astronomy, and provides a useful thread for organizing an introductory survey course. It also has the useful advantage of emphasizing the great age of systems in astronomy as well as providing examples of the way in which physical laws influence the development and formation of systems. Thus this goal has important connections with points 1-3 above.

7.) *Some knowledge of related subjects (e.g., gravity and spectra from physics) and a set of useful “tools” from related subjects such as mathematics.*

This recommendation speaks for itself. Most of us recognize the many ties between astronomy and related fields like physics, chemistry and mathematics; there is no reason not to explore these with our students. Such exploration is particularly important given the fact that, for many students, Astro 101 is the *only* college-level science course they will take. Why not, then, use it as an opportunity to talk a bit about atomic structure or the chemistry of the earth’s atmosphere? It is a useful lesson that no science operates entirely free of links to related fields.

8.) *Acquaintance with the history of astronomy and the evolution of scientific ideas (science as a cultural process).*

Again, this recommendation is self-evident. The notion that scientific ideas evolve, and what drives that evolution, are useful lessons in an age that is highly skeptical of scientific claims. Furthermore, the history of astronomy provides some wonderful examples that illustrate some of the goals listed above. Finally, many of our students may be history, government or literature majors whose interests can be piqued by some reference to the long history of astronomy and its interleaving with world history.

9.) *Familiarity with the night sky and how its appearance changes with time and position on earth.*

Notice that this recommendation appears last on a long list. Astronomy is not just constellations and lunar phases. Nevertheless, an understanding of why some constellations are circumpolar and why the full moon is highest on the meridian in the winter is intrinsically interesting, and part of our cultural heritage. More important, we would argue, is that familiarity with the night sky and its rhythms allows students (and graduates) to continue to draw inferences about those rhythms. You do not need to be *told* that the crescent moon can never be seen far from the sun if you have observed that phenomena and figured out why it is the case. So we would not urge a tremendous amount of time be devoted to teaching all these topics, but rather that the students, with some guidance, be encouraged to observe and to begin to draw *their own conclusions* about the pattern of the sun, moon and stars.

GOALS (SKILLS, VALUES, ATTITUDES)

When we turn to goals affecting student skills, values and attitudes, the recommendations of the department leaders necessarily become somewhat more general. There is clearly a wider latitude available for reaching some of these goals than might be the case for the more specific, content-oriented ones listed above. Nevertheless, we will try to illustrate or explain each of these points.

1. Why students should be exposed to

The excitement of actually doing science

This is simply a recommendation to avoid “plug and chug” problems or lab exercises, and instead provide our students with those requiring some real thought or even direct, hands-on experimentation. If one moves in this direction, one can also offer the possibility of joint work by groups of students, again modeling the way we actually do science. Encouraging students to extend what they have learned in Astro 101 classes to their own daily experiences and observations (e.g., relating lunar phase to the time of day the moon is visible) could also help. A further means of reaching this goal is to provide our students with the life stories of actual scientists (including ourselves!), emphasizing the personal struggles they went through to make their discoveries. We are in science because we are excited by discovery; why not share our excitement?

The evolution of scientific ideas (science as a cultural process)

Our scientific understanding does evolve dynamically, with change induced by both new observations and new theoretical paradigms. The Curtis-Shapley debate, after all, was only 75 years ago (with the more “famous” astronomer on the wrong side), and our understanding of cosmology has changed radically in the past decade. Astronomy, with its long history and many elegant examples of the gradual evolution of scientific understanding, provides a particularly useful vehicle to explore the development of scientific ideas, and the nature of scientific debates. We can expand on the brief synopses of the history of astronomy given in most textbooks to illustrate the evolution of our understanding of the cosmos, the influence on science of its cultural context, and the impact of new scientific models on culture. The reintroduction of heliocentric ideas by Copernicus, Kepler and Galileo is an obvious case. But there is no reason not to pursue this same goal in later portions of an Astro 101 course (the recognition that fusion solved the long-standing energy problem of the Sun; the conflict between Steady State and Big Bang cosmology, and why the latter triumphed; etc.).

2 Why students should be introduced to how science progresses, and why they should receive training in the following areas.

In providing some supporting arguments (and illustrations) for this set of goals, we have slightly rearranged the order for clarity of presentation.

Analyzing evidence and hypotheses: hypothesis testing

Observations help us choose between competing hypotheses. Historically, perhaps the two most famous were those of Ptolemy and Copernicus. Since both (crudely) accounted for the observed properties of planetary motion, it was not until Galileo’s discovery of the phases of Venus that compelling evidence was found against the Ptolemaic model. Similarly, the discovery

of the slowing-down of pulsars gave us evidence in favor of the rotating neutron star model of pulsars. It can be a fascinating classroom exercise to present students with two possible hypotheses, both of which account for some data, and ask them to propose observations which would choose between the two. And it can be a fascinating exercise to explore how, in science, unambiguous evidence can be found, whereas in other fields (philosophy, art criticism) there is simply no such thing as unchallenged evidence. This is a lesson we hope students can carry beyond the Astro 101 classroom.

The roles of observation, experiment, theory and models

Here is an opportunity to explore the complex relationship between theory and observation. Often we find that, in the absence of any theory, observations do not mean very much. Thus we had known for centuries that the moon is covered with craters--but only after we built a theory of the formation of the solar system did we realize that these craters are the scars left over from that process. Conversely, observations often reveal that the cosmos is far more interesting and diverse than our theories had led us to believe--what planetary scientist could have possibly predicted the amazing diversity of the satellites of Jupiter?

Critical thinking (including skepticism)

Skepticism is the most revered of scientific virtues. It is important to combat the view that science is no less dogmatic than, say, revealed religion. Our students may be surprised to learn that even our most cherished theories are subject to doubt and constant scrutiny. We can discuss *under the same rubric* the ongoing observations designed to test the predictions of General Relativity, and those designed to test the predictions of astrology. When both are looked at skeptically, GR survives the challenge; does astrology?

How to make and use spatial/geometrical models

We are lucky, when trying to reach non-science students, that astronomy has such a strong visual component. Students who find mathematics intimidating can enjoy the challenge of analyzing spatial/geometrical models. Thus, in thinking about the moon's phases, we can start with the simple fact that the crescent moon sets at sunset, whereas the full moon rises at sunset. Similarly, the fact that the earth is moving can be demonstrated by analyzing how the Doppler shifts of stars are distributed over the sky, or the dipole pattern in the cosmic microwave background. Let us add one more specific example: ask students to think through the claim that because the solar day is slightly longer than the sidereal day, the Earth must rotate in the same sense as its yearly revolution around the Sun.

Quantitative reasoning (and the ability to make reasonable estimates)

Non-science students are understandably leery of quantitative thinking, but we owe it to them to make them do it. Here is a good opportunity to emphasize that the true test of a scientific theory is that it account *quantitatively* for data. Thus both the theories of Copernicus and Kepler accounted *qualitatively* for Brahe's observations—but only Kepler's did so in detail. It can be a real surprise to our students to learn that the smallest of discrepancies between a theory and observation is sufficient to entirely discredit the theory. It is also interesting to emphasize that historically this is a recent notion: the ancient Greeks did not think this way, nor did Copernicus. It can also be an enjoyable discovery for them to find that they themselves can make reasonable

estimates (How many barbers are there in America? How many stars can one see naked eye on a given night? How much carbon dioxide is there in the atmosphere of Mars?).

The role of uncertainty and error in science

Discussed briefly in an earlier section.

3. And we should leave students more confident of their own critical faculties; inspired about science in general and astronomy in particular; and interested in, and better equipped to follow, scientific arguments in the media.

It may be no surprise that non-science students find science intimidating, but we are surprised when they find it dull—just a whole lot of facts to be memorized. It may be that, if we as a community of educators start to move in the new directions that have been identified by these two workshops, we will be able to recapture our students' interest and goodwill. If we can do this, we will have done them a great service.

We should aim for student learning and attitudes that *last*—not just until the final exam but for the rest of our students' lives. We want them to read newspapers or watch TV with appropriate skepticism, and some confidence in their own abilities to analyze scientific (or pseudo-scientific) claims. This too would be a service to our students, and to our nation.

Finally, it would be a service to our students to leave them inspired both by the beauty of the night sky and its comprehensible rhythms, and by the progress astronomers have made in understanding the Universe we live in.

Astro 101 courses that leave students with these benefits may well be challenging but surely not dull.

II.D SOME STRATEGIES TO ACHIEVE THESE GOALS

The participants in these two meetings were well aware that to achieve the goals listed above will require substantial changes in the way we teach, staff and support courses like Astronomy 101. Each group of participants therefore spent considerable time in discussing strategies that could help individual professors and departments reach their goals, without ignoring financial and staffing constraints. We were frequently reminded of the need to be realistic when planning curricular reforms, and of the barriers to systemic changes.

Nevertheless, there was wide support for both the goals listed in section II.C and for developing strategies to meet them. Not surprisingly, there were larger differences in the lists of strategies from the two meetings than in the lists of goals. We present here the union, not the intersect, of the two lists of strategies. No attempt was made to gain consensus agreement on any particular strategy, to prioritize the suggestions, or to make the lists from the two meetings agree. Our philosophy here is to lay out as many strategies as possible, with the expectation that individuals, departments and funding agencies will select those that best fit their circumstances. And we recognize that circumstances in a large research university with over 2,000 Astronomy 101 students per year differ substantially from those in liberal arts colleges with perhaps 50–100 students, and in turn from those in community colleges. It is also the case that the recommendations emerging from the meetings are addressed to different parties or audiences: to individual professors, departments, professional societies, etc. Hence we have grouped the 30–40 recommendations according to the primary audience they address. Finally, we add the

obvious remark that many of these strategies would be equally effective in improving introductory courses for majors, upper level astronomy courses for undergraduates, or even graduate courses.

In many cases, we have added some brief explanatory comments following a recommended strategy.

1. Some Strategies for Individual Instructors.

- Develop and announce clearly a set of goals for each course. What do you, the instructor, want your students to learn? To carry away from the course? It will help your students to know what *your* aims are. Section II.C, of course, provides a starting point for such a list.
- Make assessment (tests, home works, labs) match these goals. If your goals are as broad as those listed in sections 3, your tests should reward deep understanding, not mere memorization. We recognize both that assessments of true understanding rather than of content are harder to frame, and that there are few good examples of such tests available in astronomy (see recommendations to the astronomical community below). And assess your own teaching methods and course structure: have *you* met your goals?
- “Less is more:” Focus on material that can help students meet the goals. Do students really need to know stellar spectral classification (and memorize OBAFGKM)? *How* we determine the temperature and chemical composition of objects light years away from us is a question with deeper import, and one more likely to promote student understanding consistent with the broad goals of section II.C. To promote deep understanding may require a reduction in the number of areas of astronomy covered, or in the detail with which they are presented. Understanding that nuclear fusion powers the stars (and that chemical burning cannot) is an important lesson; the details of the CNO cycle are not.
- Only if *we* focus our teaching and stop insisting on covering the whole field thinly will textbook writers alter their approach.
- Stress *how* we know what we know, not just the results. One example is the measurement of stellar radii. A few radii we can measure directly, by interferometry, but others we calculate from temperature and luminosity.
- Teach by using unifying themes or “stories” (as opposed to the usual planets-stars-galaxies sequence). The evolution of physical systems (planetary surfaces, stars, the universe as a whole) is one example of a unifying theme. So too would be a conscious focus on “*how* we know what we know.”
- Teach from visual images. Astronomy is richly provided with compelling images. These have immediate appeal; more importantly, if we use them effectively, we can get students actively involved in forming scientific judgments on the basis of their own observations and thus improve their deductive skills. Having students look carefully at detailed images of the Martian surface, for instance, can help them frame arguments for the existence of a Martian atmosphere (airborne dust, sand dunes, etc.). Likewise, color photos of spiral galaxies can be used to illustrate many facets of star formation, the difference between PopI and PopII, etc.

- Separate important facts and physical laws from (mere) terminology. Avoid jargon, but also be careful of technical terms we take for granted; see Morrison (2002) for some cautionary remarks.
- Engage students in alternative (and more active) learning strategies, and try new teaching methods. There are well-researched ways to improve student interest, participation and performance even in large enrollment classes (see e.g. appendix C or Mazur, 1997). Many require little or no “re-tooling” by the instructor. Merely trying a new technique is only part of an effective strategy; its results must also be carefully assessed. Does a new technique “work,” in the sense of helping your students meet the goals you have set for them?
- Connect astronomy, where appropriate, with the daily lives of students. Naked eye observations of the patterns of the sun and moon offer one obvious possibility, but there are plenty of possibilities opened up by more modern physics as well. Atomic spectroscopy explains the colors of “neon” lights as well as properties of stellar spectra, for instance.
- The fact that Astronomy is a human enterprise can be illustrated by talking about astronomers as individuals, or by involving students in your own research activities or interests.

2. *Strategies for Both Departments and Individual Instructors*

Next we list some of the strategies that emerged in the two national meetings that might be appropriate either for individual instructors teaching Astro 101 *or* for departments as a whole. Perhaps most fruitfully, these could be employed jointly by those teaching Astro 101 and department leaders.

- Redesign classrooms, curricula and teaching strategies (and assess the results). This article makes a case for the redesign of Astro 101 curricula. But the design and use of classroom space also can play a role. For instance, the traditional lecture hall with fixed seats does not make it easy for classes to break into small groups for peer instruction. Departments may also want to consider whether a large lecture, supplemented by smaller discussion sections, is or is not a better model than smaller 20-40 person classes, each taught by an instructor (but presumably without additional discussion sections). We offer no prescription, but the classroom and course design should obviously be consistent with the curricular goals. Equally, both present practices and any changes should be carefully assessed: do they improve the experiences and learning of your students?
- Take advantage on ongoing programs that offer training for both faculty and teaching assistants in science pedagogy or other opportunities for faculty development. These can be in-house, or make use of programs provided by the AAS or AIP, for instance. Among the latter are ongoing sessions at AAS Meetings, as well as yearly workshops for new faculty in astronomy.
- Learn from educational reform efforts in other disciplines (and establish links to other departments that are redesigning similar courses). To give one example, physicists are ahead of us in promoting, practicing and evaluating educational reform.
- Forge links to local community colleges also teaching courses like Astro 101.

- Meet regularly with representative students enrolled in courses like Astro 101. These and the following two strategies are variations on the theme of finding out from the students themselves how their learning is progressing.
- Consider having faculty who lecture 101 also lead one discussion group.
- Use undergraduate preceptors, peer tutors or peer learning guides (see, for instance, Dick McCray's experience as described at <http://jilawww.colorado.edu/~dick/>).

3. *Strategies for Departments*

- In addition to the recommendations listed above, the workshop participants made several others to astronomy departments interested in the reform of Astro 101. Recommendations to departments as a whole include:
 - Forge links with schools of education, to learn from education experts and to promote astronomy as a vehicle to train pre-service science teachers. We believe both could benefit from such contact; there are positive examples in our field such as programs at the Universities of Arizona, Colorado and Wisconsin.
 - Invite science education experts to give talks, consult, etc. Why not include a presentation on education or pedagogy in each year's list of colloquia or visitors?
 - Include opportunities for training in pedagogy and other faculty development in start-up packages for new faculty. In most cases, these would add little to the cost of a package, yet could make a substantial difference in the success of a young faculty member in a teaching/research career. The AAS offers a yearly workshop for new faculty in astronomy each fall, in collaboration with the AIP.
 - Consider faculty positions in the field of science education research, as institutions such as the Universities of Arizona and Virginia have done.
 - Ensure that institutional reward structures recognize excellence in teaching and education research. Note that the AAS has joined the APS in endorsing the value of research in astronomy education (see www.aas.org/governance/council/resolutions.html on the AAS website).
 - If your Astro 101 course is a good model of innovative pedagogy, classroom use of IT and other teaching reforms, emphasize this fact to your deans and administrators.

4. *Strategies Recommended to Professional Societies (AAS and ASP)*

- Highlight "best practices" in astronomy education. The *Astronomy Education Review* (aer.noao.edu) is in part dedicated to this goal.
- Schedule more training and mentoring sessions on science pedagogy and faculty development at society meetings. (Under active discussion at the AAS; the ASP and AAS jointly sponsor "Cosmos in the Classroom" for Astro 101 instructors in both universities and community colleges.)
- Provide and improve clearinghouses such as Web sites for astronomy education resources, and review the material posted. The AAS Web site, www.aas.org/education, is a start. The NSF has recently funded a joint venture by several societies with the acronym ComPADRE:

this will provide reviewed and annotated resources for those teaching introductory courses in both physics and astronomy. See www.compadre.org.

- Reach out to smaller schools and community colleges teaching Astro 101, in partnership with the AAPT and other organizations.
- The AAS in particular should provide a clear statement on the importance it places on education. [We should note that since the summer of 2001, the Society has responded in a number of ways. The Education Office has been revamped, and a Director of Educational Activities, Susana Deustua, has been appointed. The AAS Council is on record as supporting the value of astronomy education research (see the posting on the AAS Web site, www.aas.org/governance/council/resolutions.html). The current AAS president, Caty Pilachowski, has made clear her personal enthusiasm for the education efforts of the Society in a recent piece in the *AAS Newsletter*.]

5. *Recommendations to Funding Agencies*

- NASA should move beyond its Minority University Education and Research Partnerships to more broadly support innovation in undergraduate courses like Astro 101. While the initial mandate for NASA education activities made reference to K-14 education, the greatest NASA attention has so far been focused on K-12 education (and on the support of graduate students). The opportunity to improve the scientific understanding of in excess of 250,000 college students a year, by reaching out to Astro 101 professors, is a substantial one that NASA should take seriously.
- NSF funding in support of initiatives in undergraduate education should be broadened to reach mid-career faculty. Awards such as NSF's prestigious Early Career Awards are designed for junior faculty, and its Distinguished Teacher Scholar awards focus on a small number of senior scientists proposing large-scale educational reforms. But there appears to be insufficient support for scientists in the middle of their careers, when many develop their interests in education.
- The NSF should consider establishing an REU program or related opportunity for the growing number of undergraduates interested in science pedagogy. Presumably this would extend beyond just astronomy to all sciences, or perhaps just all physical sciences.
- We applaud the leadership shown by both NSF and NASA in promoting science education. We hope both agencies will continue to allocate significant resources to research in science pedagogy, and to astronomy education in particular.
- Both agencies should promote and support partnerships between schools of education and astronomy departments, and between large and small institutions teaching similar courses.

6. *Recommendations to the Astronomical Community*

- Highlight and circulate "best practices" in astronomy education. Professional societies can and do play an important role, but this is a responsibility for all members of the community.

As but one example, when we list our annual accomplishments in observatory reports, do we include educational innovations?

- Provide guidance to Astro 101 instructors on the connections between the usual content areas, such as stars and planets, and the broader goals listed in section II.C above.
- Develop textbooks consistent with the goals listed in section II.C above. Remember the “less is more” philosophy advocated by the department leaders participating in these meetings.
- Develop assessment instruments that evaluate progress towards these goals. These are crucially needed. Both meetings recognized the need for a databank of sample test questions and strategies that properly assess deep understanding, not mere memorization.
- Support good astronomy education Web sites, and review their contents. Both the *Astronomy Education Review* and ComPADRE (see above) are good starts.
- Learn about educational reform, both in astronomy and in other related sciences.
- Develop proper business plans and budgets, both capital and operating, for all educational innovations. This advice is directed in the first instance to departments planning educational reforms. They will not be self-sustaining if they are fiscally unreasonable.
- Apply appropriate pressure to deans and others for funds to support pedagogical training for new and current staff and for TA’s, for additional support for TA’s, for curricular reform, and for revamping and refitting classrooms to make them more hospitable. This is the reverse side of the need for fiscal prudence. There are times when a modest increase in funding could make a substantial difference in the success of a popular course like Astronomy 101. The participants at these two meetings, many of them department chairs, recommended that we should not be shy in asking deans and provosts for financial support. The present two authors would extend this argument by suggesting that individuals not be shy in asking department chairs for similar support and resources!
- Perhaps our most important recommendation of all is that the astronomical community must revise its rewards structure to recognize excellence in teaching or astronomy education research. Until we recognize excellence in the classroom, and honor those who teach challenging classes informed by research in how students learn, reform will come slowly and grudgingly. We will continue to be surprised that our students find dull a subject we love. As a community we have an opportunity to move in the new directions recommended here, and consequently to make our mark in improving the science literacy of millions of our fellow citizens. Grasping that opportunity will require us all to broaden our view of what constitutes excellence in our field.

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APPENDIX A Demographics of Enrollments in Astro 101

Records of yearly enrollments in introductory astronomy courses for nonmajors are not kept by the AAS, the AIP or any other body. The best available published assessment of enrollments in Astro 101 is the article by Andrew Fraknoi (2001) in the first volume of the *Astronomy Education Review*. He estimates that approximately 250,000 college students take Astro 101 each year. To this, add a further 20,000 in Canada (estimate by John Percy of the University of Toronto).

As Fraknoi points out, the AIP *does* maintain statistics of enrollments in introductory astronomy (and physics) courses in the ~800 US institutions that have physics and/or astronomy departments; left uncounted are enrollments in more than 2500 institutions not surveyed by the AIP because they do not have physics departments. The AIP *Enrollments and Degrees Report* for July 2002 (Mulvey and Nicholson) shows that 168,000 students are enrolled in astronomy courses in the institutions surveyed (and of course the overwhelming majority of these are in various flavors of Astro 101, not courses for majors). Of this total, 53% are enrolled in Ph.D.-granting institutions, and the remainder in colleges and universities that offer Masters or Bachelors degrees in physics and/or astronomy.

To this total, Fraknoi (2001) suggests adding ~100,000 students per year who take their astronomy in colleges without physics or astronomy departments, including principally the nation's community colleges. The 2002 AIP Enrollments and Degrees Report provides another avenue to check this figure. By AIP figures, 183,000 students took either algebra-based or "conceptual" physics in 2000; the AIP also report figures of ~60,000 students in similar courses in community colleges (taken from earlier work by Neuschatz *et al.*, 1998). If we assume—probably conservatively—that the same ratio applies to astronomy enrollments, we can then estimate that 50,000-55,000 community college students are taking astronomy each year. This figure is lower than Fraknoi's estimate of 100,000 but does *not* include enrollments in the ~1400 4-year colleges that do not have astronomy and/or physics departments (and hence are not surveyed by the AIP).

We conclude that Fraknoi's estimate of 250,000 enrollments in Astro 101 is appropriate and perhaps even conservative, especially if we include enrollments in such courses in Canada.

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APPENDIX B Pre-Meeting Questionnaire and Responses to It

In advance of the two national meetings, a pre-event survey was designed and sent to all participating institutions. The survey had two purposes: to gather demographic information on how (and to whom) Astro 101 is currently taught in these leading institutions and to help frame the agenda of the two meetings.

We reprint the survey in B.1, and summarize the responses to the survey in B.2.

B.1 PRE-MEETING QUESTIONNAIRE

This survey is to be completed by attendees to the spring 2001 meetings for department chairs addressing the goals of and reforms in introductory Astronomy courses (referred to as "Astronomy 101"). If more than one person from your department will be attending the meeting, only one of the participants needs to complete this survey. The data acquired by this survey will be collected and discussed at both the May 11-12 meeting at The University of California, Berkeley and the June 15-16 meeting at Harvard University. The meeting organizers thank you for your time and consideration. We ask that you return this questionnaire by February 15, 2001 to Gina Brissenden: 303-E Eagle Heights Dr., Madison, WI 53705. This will allow us time to assess and tabulate the responses before the May and June meetings.

Please indicate the appropriate response to each of the following:

1. I fill the following role concerning Astronomy 101 in my department.

- Department Chair
- Instructor of Introductory Astronomy
- Other interested faculty or staff (describe _____)

2. The Astronomy 101 course my department offers has a typical class size of

- Fewer than 50 students
- 50-200 students
- 200-500 students

- Greater than 500 students
- Unsure

3. The Astronomy 101 course my department offers has a well defined observational or instructional lab associated with it.

- Yes
- No
- Unsure

4. The following technological teaching aides are available in the classroom/lecture hall where Astronomy 101 is taught:

- Projection screen
- Overhead projector
- Slide projector
- VCR with display
- Opaque document projector
- Desktop Computer
- CD-ROM drive
- DVD drive
- LCD plate
- Computer projection unit
- Other _____
- Unsure

5. The following technological teaching aides are frequently and effectively used by the instructor of Astronomy 101:

- Projection screen
- Overhead projector

- Slide projector
- VCR with display
- Doc camera
- Desktop Computer
- CD-ROM drive
- DVD drive
- LCD plate
- Computer projection unit
- Other _____
- Unsure

6. Please indicate which of the following best describes how the role of Astronomy 101 instructor is filled in your department.

- A professor or associate professor typically teaches the Astronomy 101 course.
- A post-doc or other staff holding a PHD or MS typically teaches the Astronomy 101 course.
- A graduate student typically teaches the Astronomy 101 course.
- Other _____
- Unsure

7. If there are small recitation or laboratory sections in addition to Astronomy 101 lectures, indicate which of the following best describes how they are staffed.

- A professor or associate professor
- A post-doc or other staff holding a PHD or MS
- A graduate student or several graduate students
- Other _____
- Unsure

8. Please indicate which of the following best describes how the role of Astronomy 101 instructor is filled in your department.

- The Astronomy 101 course is taught by the same individual semester after semester.
- The Astronomy 101 course is taught by several different individuals who rotate the responsibility.
- The Astronomy 101 course is taught by someone different almost every semester.
- Unsure

9. Please indicate all of the following teaching methods/techniques that you are familiar with.

- Peer learning
- Inquiry-based learning
- Collaborative learning
- Student teaching and learning activities
- Interactive lecture demonstration
- In-class writing
- Constructivist teaching methods
- Discovery learning

10. Please indicate all of the following teaching methods/techniques that are currently employed in your department's Astronomy 101 course.

- Peer learning
- Inquiry-based learning
- Collaborative learning
- Student teaching and learning activities
- Interactive lecture demonstration
- In-class writing
- Constructivist teaching methods

- Discovery learning
- Unsure

11. In comparison to other undergraduate courses offered by your department rate the priority you personally place on Astronomy 101. (1 indicating highest priority)

- 1 2 3 4 5

12. In comparison to other undergraduate courses offered by your department rate the priority your department places on Astronomy 101. (1 indicating highest priority)

- 1 2 3 4 5

13. Please indicate which of the following is the greatest contributing factor in your response to questionnaire item number 11.

- Astronomy 101 allows our department to serve a large number of students increasing departmental resources, such as funding or FTE.
- Astronomy 101 is a requirement for many non-physics majors
- Astronomy 101 serves to increase science literacy.
- Astronomy 101 is a good course to recruit new astronomy or physics majors
- Astronomy 101 addresses material that is too trivial and the students earn a grade that doesn't reflect good learning.
- Astronomy 101 is a difficult teaching position to fill; the faculty is not interested in taking on the burden.
- Other _____

14. Please rate your ability to affect changes in your department's Astronomy 101 course. (1 meaning you feel highly influential)

- 1 2 3 4 5

15. Please rate your involvement in determining goals and outlining curriculum for your department's Astronomy 101 course. (1 being highly involved)

- 1 2 3 4 5

16. Please rate the funds your department devotes per Astronomy 101 student in comparison to other undergraduate courses offered. (1 indicating that Astronomy 101 gets larger per student funding)

- 1 2 3 4 5

17. Do you or does your department in general encourage young faculty to teach Astronomy 101?

- Yes, strongly (explain _____)
- Yes, but the decision is left to young faculty
- No, but the decision is left to young faculty
- No, it is strongly discouraged (explain _____)

18. Please list three or four pressing issues connected with your department's "astronomy 101" course or courses that you would like to see us discuss this coming spring.

B.2 RESPONSES TO THE QUESTIONNAIRE: ASTRO 101 AS IT IS NOW TAUGHT

A total of twenty-two responses to the survey were collected. Respondents were quite evenly divided between astronomy department chairs and vice-chairs (12) and Astronomy 101 instructors (10).

The survey results give the following picture of the general layout of the introductory astronomy course offered by the respondents' departments. The type of course offered fits largely into one of two categories: 10 respondents indicated that their department offered a one semester survey type course, and 10 indicated that a two semester topical course was offered. Astronomy 101 was unanimously described as a large lecture course; roughly half of the 101 classes include a recitation section (10) and two thirds offer a lab (15). The lecturing is typically done by a professor or associate professor (21) while the labs and recitation sections are handled by graduate student staff (all applicable respondents).

The survey showed that the participants felt that the course received mildly below average funding per student from their departments, the average response being a 3.17 on a 5 point scale (1 = highest funding). Despite this, the classrooms in which the introductory astronomy course is taught were reported to be well equipped, with nearly all of the participants having access to (and using) slide projectors, overhead projectors and VCRs. And roughly two thirds reported access to and use of computers with projection capability.

Our participants ranked introductory astronomy as a very high priority course within their department. The average response on a 5 point scale (1 being highest priority) was 1.47. The respondents indicated that their main reasons for the high ranking were as follows: "increases science literacy" (18), and "large enrollment increases the department's resources" (13).

When asked about teaching methods employed in the Astro 101 course, roughly half of our participants were familiar with the following: peer learning (10), inquiry based learning (10), and interactive lecture demonstrations (10). However, a comparable number of respondents indicated that they were not familiar with any of the methods listed (9). The methods known to be employed in the course echoed those that were most familiar, but 13 respondents indicated that they were unsure of which, if any, of the techniques listed were being employed.

There were four recurrent themes of concern that the survey participants indicated they would like to see discussed at the national meetings. The most common responses included a desire to discuss ways in which student motivation could be improved (8), and a lack of the availability of good activities for large lecture settings (7). Two other common responses showed an interest in discussing how to pick a good astronomy text (5), and what kinds of computer based activities and resources are effective (4).

APPENDIX C Input from Experts

As noted in section II.B, several experts in astronomy (or physics) education made presentations at each of the two meetings. These were typically 1/2-1 hour in length (see Table 1 on page 12 for details).

In this appendix, we provide a summary of three of the presentations, as samples, and also provide references to the published work of our other experts related to the topic they addressed.

C.1 PRESENTATION BY ELAINE SEYMOUR

“Changes in our Understanding of What may be Needed in Undergraduate Science Education: What can Astronomy Contribute?”

Elaine Seymour
 Director: Ethnography & Evaluation Research
 University of Colorado
 Boulder.

I describe some features in the changing landscape of activities intended to improve both quality and access in science, mathematics, engineering and technology (SMET) undergraduate education over the last decade. Shifts in the locus of concerns—from emphasis on the supply and educational preparation of SMET majors to the goal of making science more accessible to all students—offer distinctive opportunities to faculty teaching introductory astronomy classes. The more inclusive student profile of these classes (compared with introductory classes leading to science and engineering majors) offers the opportunity to engage students with a limited appreciation of science (or less certainty about their ability to participate in it) and to encourage and support undergraduates who are considering K-12 teaching as a career, but who need stronger numeric and scientific preparation. Astronomy faculty could make a significant contribution by developing their introductory classes in ways that address the least attended to aspect of educational reform in the sciences—the national shortfall in qualified mathematics and science teachers at all K-12 levels.

Astronomers interested in rethinking their teaching of introductory classes have the advantage of building upon work already done by both national consortia and by independent initiatives in mathematics, physics, chemistry, biology and engineering—and learning from them what works better than what. Collectively these initiatives have been successful in highlighting the need to shift the classroom emphasis from teaching to learning, and in working out how this may be accomplished in a variety of contexts. Refocusing classroom practice upon gains in student understanding, reasoning, application, and learning retention is accomplished through more active and interactive forms of teaching that place greater responsibility on students. Largely by workshop outreach, science education reform initiatives have drawn a growing number of faculty into a process of professional development that includes: understanding the theoretical and practical contributions of learning theory, the importance of articulating learning goals and aligning them with course assessments, and using assessment both as feedback to teachers and to further engage students in their own learning. Across departments and institutions, the shift towards learning has led to the rediscovery of teaching and educational

scholarship as professional activities. It has generated some rethinking of professional relationships with colleagues in education, assessment and evaluation research, and in other SMET disciplines. It has also prompted redesign of professional education for graduate students and entering faculty, and of the facilities in which SMET courses are taught. Making working connections with faculty in these parallel initiatives offers astronomy faculty the opportunity to select from this collective experience—and from a wide array of documents and on-line resources, classroom products, and workshop opportunities—in order to develop strategies that define the distinctive contribution that introductory astronomy education can make to the national target of “science for all.”

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C.2 NOTES ON A PRESENTATION BY DICK MCCRAY OF THE UNIVERSITY OF COLORADO (WITH ASSISTANCE FROM ELAINE SEYMOUR AND LIANE PEDERSEN-GALLEGOS)

“An On-Line General Astronomy Class”

(see cosmos.colorado.edu/cw2/courses/astr1020/text and Seymour *et al.* 2002, *Science Education* 86, 79)

Method

In-depth interviews with focus groups w/ all students in three semesters:

Spring 2000	53 students in 16 focus groups
Fall 2000	98 students in 17 focus groups
Spring 2001	142 students in 32 focus groups

Interviewed all TAs.

Last 2 semesters, used the Student Assessment of Learning Gains (SALG) instrument, as well.

Evaluator attends all weekly TA meetings throughout all 3 semesters.

Observations

Resistance is normal—also found in 6 years of chemistry consortium research. Good news is that it fades as changes become the standard.

These are impressions only, at this stage, as full data analysis is still underway.

Resistance to Change: Sources

- 1 Previously successful students “know the system” and how to get A’s or just get through—don’t like this system to change.
- 2 For those who have strategies in place to do the minimum, and who are thus proponents on the most passive system possible, resist change because it means they now have to be active learners.
- 3 General resistance to change simply because it requires the effort of adjustment
- 4 Lack of confidence in one’s own/other students’ knowledge/abilities. Reliance on the authority of the professor.
- 5 “Consumer perspective”: “I’m paying tuition so the professors will do the teaching.”
- 6 Fear of technology: being inhibited by computers.

In sum, changes in pedagogy expose students' bad learning habits: memorization and other short-term memory strategies; doing the minimum work; formulaic answers instead of insightful, thoughtful answers.

Overcoming Resistance to Change

We told Professor McCray from the beginning what we had found out about resistance to change in our work with the ChemConnections project. He was especially careful about sign-posting from the first day of class. He encountered much less resistance to change by doing the following:

- Sign-posting: early and often. Informing students of what's coming up, how aspects of the course fit together (both the content and the structure of the course), and how what is currently happening fits with both the past and future. This helps students appreciate the meaningfulness of the pedagogy.
- Keep it current: students don't expect cutting edge information to be "precanned" and are more open to innovation/change in this context
- Emphasis on the intent of change: to improve on what we have, what we know, not just to "experiment on" the students. (re student sensitivity to "being a guinea pig")
- Sensitivity to grading issues: shoring up the trust factor is important w/change and w/any increasing complexity that may come with change. When students are reassured they can still achieve the grades they are accustomed to, they are more open to change.
- Reassure students that they are learning, and that what they are learning is important, relevant, and will stand them in good stead in future classes.
- Responsiveness of professor to input from students, TAs, anyone else on the learning team, and the evaluators.
- Keep the students engaged and interested: enthusiasm of the professor helps, as do interesting activities for the students—keep the spark alive.
- Bonding between students and the professor and TA and fellow students contributes to high morale and increases receptivity to change.
- Know the culture on your campus: we have an element of the "ski school" at CU. Knowing that the student norm for many is to attend class as little as possible in order to attend to the ski slopes as much as possible tells us what we're up against. Mandatory class attendance may be more important for some schools than others, for this reason.

In sum, there has been a surprisingly high level of receptivity to the changes made in Professor McCray's classes, given what we had come to expect from our work with the chemistry consortium. (Another important factor with chemistry is the service major problem.)

*Other Observations**Scaling Up*

This is tricky, and difficult to track when change is ongoing throughout the semester.

Two scales: Overall class; learning teams.

When asking students about optimal size of learning teams, we find 3 things:

- 1 Students will often cite the size of their own teams as ideal, even though these team sizes may vary significantly, indicating there is a wider range of acceptable team sizes than we may have expected...
- 2 The nature of the group projects needs to correspond to the size of the group: with lots of work to do, students favor larger groups so the workload is more manageable
- 3 There is a nearly universal preference among students for smaller classes/work groups (except for work groups in which there is a heavy work load).

Undergrad TAs

Success with Dick McCray's teams can be attributed, in part, to:

- Weekly team meetings that keep everyone updated
- Collegial treatment of TAs: Responsiveness to TA feedback
- Attention to individual team issues

One benefit of undergraduate TAs: comfort level of working with peers.

What we've learned: there is a need for more formal training of undergraduate TAs, particularly when it comes to facilitating group work.

Testing

Needs to be coordinated with other pedagogical changes. Testing that is valid in students' eyes go a long way toward promoting student receptivity.

Group Work

What we've learned:

- Starting with a group project, such as designing a web page for each learning team helps to set a tone for group work
- Group work depends on assignments that require team efforts. Students' fallback is to work individually whenever possible

- Inevitably, some groups are going to have stronger student leadership than others. Identifying the groups that need the most academic support and then providing it works best. We suspect there is a pattern of weaker groups by virtue of scheduling: students in a given non-science major who have common schedule demands in their majors are likely to find themselves on the same learning team by virtue of time available to them.

Student Assessment of Learning Gains (SALG)

Same questions asked of last 2 classes. Results indicate a small, but consistent, increase in student ratings from the first to the second semester. Areas of greatest improvement:

Specific learning gains (question #4) and

The way in which the material was approached (Aspect A).

How much did each of the following aspects of the class help your learning?

A. The way in which the material was approached

Q4: To what extent did you make gains in any of the following as a result of what you did in this class?

1. Understanding the main concepts
2. Understanding the relationship between concepts
3. Understanding how ideas in this class relate to those in other science classes
4. Understanding what real scientist do
5. Developing skills I would use as a real scientist
6. Ability to think through a problem or argument
7. Learning facts about Astronomy
8. Feeling comfortable with complex ideas
9. Enthusiasm for subject

C.3 REFERENCES TO WORK BY OTHER EXPERTS

- 1.) For Robert Mathieu's work, see the Wisconsin Center for Education Research web page, www.wcer.wisc.edu.
- 2.) Mazur, E. 1997, *Peer Instruction*, Prentice Hall. See also Crouch, C. H., and Mazur, E. 2001, *Amer. J. of Phys.* 69, 970.
- 3.) Redish, E. F. 1999, *Millikan Award Lecture: Building a Science of Teaching Physics*, *Am. J. Phys.* 67, 562.

See also Redish, E. F., and Steinberg, R. N. 1999, *Physics Today* 52, 24; and Redish, E. F., Saul, J. M., and Steinberg, R. N. 1998, *Am. J. Phys.* 66, 212.

4.) Tobias, S. 1992, *Revitalizing Undergraduate Science: Why Some Things—Work and Most Don't*, Research Corp., Tucson, AZ.

See also her book with J. Raphael 1997, *The Hidden Curriculum: Faculty-Made Tests in Science* (Plenum Press, New York), and her 1990 book, *They're Not Dumb, They're Different: Stalking the Second Tier and Breaking the Science Barrier* (Research Corp., Tucson, AZ).

APPENDIX D Assessment

During and after the meetings both formative and summative evaluations were conducted by an outside expert to assess the effectiveness of the workshops. A summary of the results of this assessment by Tom Brown (Montana State University) follows:

The goals of the meetings were to:

- Create mechanisms for the sharing of experiences and for participant learning from peers and experts
- Identify common goals for Astro 101
- Increase participant awareness of new teaching strategies and resources
- Increase participant involvement and interest in Astro 101 within their departments

A set of related evaluation questions was developed to aid both in the formative evaluation of the meetings as they progressed, and in the determination of the degree to which the above goals were met at the conclusion of the proceedings:

What sessions were the most/least informative or useful?

- Were the views of all the participants heard?
- Was the discussion passive or active?
- Who, if anyone, was dominating the discussion, experts or participants?

A set of evaluation items was developed to collect data from the meeting participants as a means of assessing progress towards the above goals and answering the questions above. These items can be broken into formative and summative indicators. Formative evaluation was taken as the first (Berkeley) meeting progressed to help gain insight on how the next session (Harvard) could be improved.

D.1 FORMATIVE EVALUATION

A total of twenty-two written response forms and four interviews were gathered at the Berkeley meeting, and twenty-two written response forms and two interviews at the Harvard meeting. Of those responding to the written evaluation forms almost all reported that they will take useful information and or ideas back to their departments and attempt to make changes to improve their introductory astronomy course. Those interviewed unanimously responded positively to this question. Specific statements indicated that the teaching strategies discussed inspired them to try some new things in their classrooms, and that the formal construction of a list of goals inspired them to re-evaluate the structure of their classes.

There was a consensus among those responding that the list of goals and strategies created was appropriate and interesting. Several commented that it was surprising that the goals were not more content oriented, but they saw this as positive and refreshing.

At the first (Berkeley) meeting two-thirds of those responding to the written evaluation forms, and all of those interviewed, called for a more strictly controlled discussion. Among this group there was agreement that useful and informative discussion was had, with one-fourth of the participants listing the discussion as their favorite part of the meeting. However, they felt that a few individuals dominated the discussion and that it tended to range off topic. Analysis of the discussion diagrams confirms this opinion.

A similar analysis was conducted during and after the second (Harvard) meeting. The results of this assessment were similar with one exception: there was no call for more controlled discussion at this meeting. Participants at Harvard all responded positively when asked about this issue. The discussion diagrams from this meeting show individuals dominating large parts of the conversation just as was the case at Berkeley. However, the perception on the part of the participants seemed to be that this was not the case. The initial uncertainty about the meeting's goals that appeared at Berkeley vanished as well. It appears that the formative evaluation taken at the first meeting allowed the meeting coordinator to take the appropriate steps to eliminate these issues. The meeting introduction was more detailed, and the participants were more aggressively prompted for comment. The Harvard participants seemed much more satisfied with the discussion as a result of these effective changes.

D.2 SUMMATIVE EVALUATION

The final piece of evaluation to discuss is the post-event interviews. Eight participants were chosen at random and interviewed via telephone to assess the meetings' effectiveness in fostering actual change in participants' attitudes toward introductory astronomy and to gain a sense of the degree to which the participants were sharing their experiences with other faculty within their departments. The interviews were conducted in December of 2001 and January of 2002. The interview questions were as follows:

- Now that some time has passed since the meeting, what would you say is the one discussion or presentation that, above all else, has made a lasting impression on you?
- Have you shared this or any other experiences from the meeting with colleagues in your department?
- What was your impression of the list of goals and strategies for Astronomy 101 that was sent out a few months ago?
- Are there any specific changes that you have made or plan to make in the way you teach astronomy as a result of your attendance at this meeting?
- In particular, has the list of goals and strategies informed your instruction?

- Do you plan on attending any future AAS sponsored meetings on introductory astronomy or astronomy education?

The post-event interviews showed some success in making a lasting impact on the participants and fostering change within their department's Astronomy 101 course. Although two participants declined to be interviewed and directly stated that the meeting did not have much of an impact on them, five of the eight people approached responded positively to the meetings in one way or another. All of these either directly made changes within their departments or, at the very least, disseminated the information that they found useful to their colleagues.

[Excerpted from “The 2001 Meetings of Department Leaders on ‘Astronomy 101’: An Evaluation of Meeting Goals” by Tom R. Brown, Department of Physics, Montana State University, Conceptual Astronomy and Physics Education Research (CAPER) Team, <http://www.aas.org/education>.]