Chapter 1

Curriculum

Teaching astronomy depends on deciding what to teach. In addition to a general discussion of desiderata, the papers in this section discuss particular programs in the U.K., China, Portugal, Hungary, and Brazil — countries that are broadly representative of world astronomy. Some related papers appear in the chapter on the developing countries.

CURRICULUM FOR THE TRAINING OF ASTRONOMERS

Jayant V. Narlikar
Tata Institute of Fundamental Research, Bombay 400005 and
Inter-University Centre for Astronomy and Astrophysics, Pune 411007, India

1. Introduction

In a discussion on the training of astronomers, the question naturally arises: "Training...but at what level?" After all, the subject of astronomy happens to be unique amongst all sciences in that it interests children and educated general public at one end and professionals at the other. Before coming to these specifics, certain general remarks will be in order.

Astronomy is a branch of science. This fact is not readily appreciated at the "lay" end of the above spectrum. Unlike other sciences, which have Earth-based laboratories in which controlled experiments are performed, astronomy has its labs located in the heavens far beyond the reach, let alone "control," of the terrestrial observer. So how can one be sure that what one sees out there is subject to the same rules and disciplines of science that govern the local laboratory experiments of physics and chemistry? Yet that happens to be so!

The basic thrill of learning and teaching astronomy lies in appreciating this fact. With suitable ingenuity, scientists have tried to overcome the disadvantages of a remote and uncontrollable laboratory: we have harnessed the latest available technology to augment our capability for collecting information. And with equal

https://doi.org/10.1017/S0252921100086280 Published online by Cambridge University Press

facility scientists have looked for explanations of very unusual and often mystifying cosmic events in terms of known laws of physics. The measure of success we have achieved has been such as to prompt Albert Einstein to wonder: "The most incomprehensible thing about the universe is that it is comprehensible."

Recently, the Government of India has set up the Inter-University Centre for Astronomy and Astrophysics (IUCAA). The Centre will serve as a centralized national facility for research workers in astronomy and astrophysics from Indian universities. Among its other programs, IUCAA will conduct pedagogical activities in these subjects at various levels. The ideas presented here form part of the on-going discussions about how astronomy teaching could be integrated with other courses in schools and universities.

2. Observational Astronomy

From ancient to modern times, light remains the main (if not the only) agent bringing information from remote corners of the universe. This monopoly of light has been broken today (but only marginally) by cosmic rays, neutrinos, and gravitational radiation. It is natural therefore that the part of the curriculum dealing with observational astronomy will contain mostly the role played by light; and so the following topics should find a logical place in "what every astronomer ought to know."

a) The nature of light

i) A description of the electromagnetic theory of Maxwell that led to the appreciation of light as an electromagnetic wave.

ii) The manifestations of electromagnetic waves of different wavelengths. Although human eyes respond only to a limited optical window, astronomers today cannot afford to ignore the other wavelengths.

iii) The role of the "spectrum," from the more familiar "rainbow" to the invisible radio or x-ray spectra. Continuum radiation and line radiation.

iv) The quantum nature of light as exhibited by the line spectrum of an astronomical object. It is important to emphasize that one of the crucial sources of evidence for quantum theory came from the Fraunhofer lines in the spectrum of the sun.

b) The role of the atmosphere

How and why does the atmosphere admit only selectively the cosmic radiation that bombards our planet? The role of space astronomy *vis-a-vis* that of ground-based astronomy.

c) The types of radiation

Although stars are the most familiar radiating sources, the astronomer en-

https://doi.org/10.1017/S0252921100086280 Published online by Cambridge University Press

counters other sources that radiate quite differently. Thus it is desirable to know the different kinds of radiation one is looking for, *e.g.*, black-body radiation, synchrotron radiation, bremsstrahlung, inverse-Compton effect, *etc.* Again, it is worth emphasizing that our information of these radiation types is based on laboratory studies.

d) Detector systems

From the human eye to the CCD system lies a wide span of technology of detectors of astronomical radiation. The curriculum should ideally emphasize the difference of detector systems for radiation of different frequencies. Why are radio telescopes so enormous in size while x-ray detectors are relatively tiny? What are the differences in techniques for measuring line radiation and continuum radiation? Why is it useful to know if the radiation is polarized?

e) Star gazing

None of the above items in the curriculum can be really appreciated without some background of the traditional method of introducing astronomy, *viz* star gazing. But modern inputs into such a program should include the invisible universe...the world of galaxies and quasars invisible to the human eye, of giant molecular clouds, infrared sources, X-ray emitters, and huge radio galaxies. Appropriately introduced, a star-gazing program not only brings the thrills of observing but it will also convey to the student the rich storehouse of information and puzzles that lie beyond the range of naked-eye observing.

3. Theoretical Astronomy

Without its theoretical component, astronomy would not be a science. The interaction between physics and astronomy has been two-fold. Contrary to the belief generally held by laboratory physicists, astronomy has contributed to the growth of our understanding of physics. Thus not only has physics helped in the elucidation of astronomical phenomena but it has also in turn been helped by the inputs coming from astronomy. Examples are the discovery of the law of gravitation (where the credit should go to the information provided by the motion of the moon and the planets instead of to the falling apple), the viability of nuclear fusion (demonstrated in the sun and the stars and yet to be reproduced in controlled form on the Earth), and the more recent vigorous brainstorming going on between particle physicists and cosmologists.

In a typical text, astronomy is described in terms of things encountered as we go progressively away from the Earth in a sequence: the planets, the sun, the stars, the Milky Way, the galaxies, clusters, superclusters, quasars, and finally, the expanding universe. This may be the correct approach in a very elementary text, but it fails to depict the physics-astronomy interaction described above.

Fred Hoyle and I wrote an elementary text (Hoyle and Narlikar, 1980) that attempts to describe this interaction. Drawing on the basic interactions of physics, we

https://doi.org/10.1017/S0252921100086280 Published online by Cambridge University Press

grouped the astronomical phenomena according to the interactions playing crucial roles therein. Typically such a grouping would be along the following lines:

a) The electromagnetic interaction

The physics of radiation mechanisms and their examples, stellar radiation (black body), radio sources (synchrotron), X-ray sources (inverse-Compton), *etc.*, acceleration of charged particles (pulsars, cosmic rays), absorption and scattering of electromagnetic waves (interstellar dust), and so on.

b) The strong and weak interactions

Nucleosynthesis in stars, cosmic rays, supernovae, the primeval universe, *etc.*

c) Gravity

Motion of planets, satellites and binary stars, stellar structure and evolution, N-body motions in clusters of stars and galaxies, black holes, the expanding universe.

For integrating astronomy with physics an approach of this kind is called for. Only then will the student really appreciate how "scientific" astronomy is.

4. The Level of Presentation

It could be argued that the above approach may be difficult to incorporate in an elementary curriculum. I do not share this point of view. Admittedly the extent of mathematics and the depth of physics that can be used in front of school children or lay audiences are very limited. But nevertheless attempts should be made to inject some science into the purely descriptive syllabus that is often found in such situations. The "how" and "why" are just as important as the "what" in astronomy.

The task is not easy! I myself made an attempt to describe stellar evolution at a purely descriptive level (Narlikar, 1984). I had to introduce a few simple formulae...but perhaps one can do better with more analogies instead.

At the high-school and undergraduate levels, one can introduce simple algebra and perhaps some calculus also, to make the presenter's task easier! The level of mathematics can be higher still at the graduate level courses.

5. Conclusion

To do justice to astronomy and to would-be astronomers, the curriculum should be such as to bring out the aim of astronomy to understand the physics behind the cosmic events and to thereby enrich our understanding of not only the cosmos but of the science as well.

References

Hoyle, F. and Narlikar, J.V. *The Physics-Astronomy Frontier.* W.H. Freeman, New York. 1980.

Narlikar, J.V. *From Black Clouds to Black Holes.* World Scientific, Singapore. 1984.

Discussion

J.V. Feitzinger: *Can you comment on TV teaching of basic astronomy in India and what plans has your institution to do this?*

J.V. Narlikar: Our Institution will be located next to the Education Media Research Centre, which has well equipped TV studios. We plan to use EMRC facilities extensively for making astronomy programs for students and the general public.

AN ASTRONOMY DEGREE COURSE IN THE U.K.: SYLLABUS AND PRACTICAL WORK

M.M. Dworetsky
Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, U.K.

1. Introduction

What is the purpose of an astronomy degree? Why should students wish to take such a course? What will they do after graduation? In what way would such a course uniquely differ from a physics degree with a little astronomy tossed in? And given that we are called upon to provide such a course, what syllabus might we teach? These are some of the questions that occurred to me as I was preparing this paper.

One obstacle to giving clear answers is that the higher education systems of various countries differ greatly in structure. As one who was trained in one system (U.S.A.) and who teaches in another (U.K.), I am perhaps in a better position than most to appreciate the differences in approach, and to weigh the advantages and shortcomings of each system. But, as Shakespeare's Dogberry said, "Comparisons are odorous," and I do not propose to do this! What I describe refers to current practice in the university system of England and Wales, and I will use my own institution's long-standing astronomy degree as an example.

2. The Astronomy Degree

The course is a three-year honours degree Bachelor of Science. There is no "breadth" requirement for students to take courses in other subjects, in contrast to the usual practice in North American colleges and universities. Normally, students arrive at our front gates at age 18, having recently obtained good results in national "A-level" examinations in physics and mathematics, roughly equivalent to success-