Chapter 5

Computers

With the widespread availability of personal computers, the role of computers in education is rapidly increasing. The chapter begins with an overview of microcomputers in astronomy teaching and a discussion of some programs either available or under development. We then read about specific personal-computer programs worked on in Italy, the U.S., Bulgaria, India, and Belgium. The next paper discusses the use of powerful microcomputers to generate classroom displays. Finally, we hear about one "paperless classroom" that uses a central computer to manage virtually every aspect of the teaching process.

MICROCOMPUTERS IN THE TEACHING OF ASTRONOMY

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1. Introduction

There are many ways to use computers in teaching. This paper discusses one of those ways: as an adjunct to the introductory astronomy course as taught in the United States.

The computer allows the demonstration of phenomena in a graphic dynamic manner, so its use can enable students to gain a deeper understanding of the material than they might when they passively listen to a lecture, look at slides, or study a textbook. In a very real sense, material presented in a computer is similar to that presented by film or video, but with one major difference: viewing movies is essentially a passive experience while interacting with a computer is an active one. Using computer simulations, the user can vary initial conditions and observe the effect of changes. This ability is the case whether the person doing the interacting is the instructor during a lecture or the student during a lab or while independently executing a homework exercise.

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Over the years, a number of papers have described specific computer programs for use in teaching astronomy. A list of available astronomical software is maintained by the Astronomical Society of the Pacific and published periodically (Mosley and Fraknoi, 1986). In this paper, I am going to take a slightly different tack and describe how to use a variety of programs throughout a one-year introductory course. I am also going to discuss a rather complex project that doesn't fit into the traditional astronomy course and that is currently being mounted at the College of Charleston.

Most of this paper discusses using computer software either for demonstrations or for laboratory exercises, since these are the prime ways I use computers in teaching introductory courses. The characteristics of the software and the preparation on the part of the instructor vary according to the type of use and caliber of students involved. Obviously, if the software is being used as a classroom demo, then it is important for the instructor to be familiar with commands and for the software to function rapidly. On the other hand, if the students are to interact with the software as homework or in a laboratory setting, then the speed of operation is not quite as important while the clarity of the instructions is paramount. When students are interacting with the computer directly, it is important to have worksheets or suggestions for report formats to accompany the programs.

2. A Sample Course

In the succeeding discussion, I am going to consider a sample course presented in the "traditional" manner. That is, I will start with the observable phenomena of the night sky and move on to the historical presentation of the development of explanations for astronomical observations, the solar system, the physics of stars, our galaxy, and external galaxies.

Observable Phenomena of the Night Sky

A very popular use of the computer (judging from the number of different programs available) is as an indoor planetarium. These have been reviewed in a number of papers elsewhere (Mosley, 1986; Mosley, 1987, Kanipe *et al.*, 1988). In this mode, the computer screen represents the night sky with the positions of stars, the moon, the sun, and the planets plotted. These programs demonstrate many of the phenomena that were observable by the ancients and that form the foundation of modern astronomy. While the same phenomena are visible today to anyone who takes the time to look (sometimes over a period measured in years), the computer enables them to be demonstrated in minutes. Early attempts at writing such programs resulted in ones that were not especially useful for educational purposes because of both the low resolution and slow speed of the early microcomputers. More recent computers, such as the IBM AT and Series 2 computers and the Apple Macintosh, have overcome these problems and can present remarkable displays that are useful as substitutes for or adjuncts to planetariums. Mosley (1988a) has suggested that two of the better ones for IBM compatible computers are "Superstar" (PicoSCIENCE, 1988) and "Visible Universe" (Parker, 1988). Superstar seems unique in that one version of it contains the entire SAO catalog. An excellent program of this type for the Macintosh which I have used is "Voyager" (Mathis, 1988). This program has been reviewed by Mosley (1988b). Screen replotting is very rapid, which makes the program useful for demonstrating time-dependent phenomena such as the diurnal motion of the celestial sphere or the motion of the planets with respect to the background stars. The program also allows relocating the observer to a point up to 100 astronomical units from the sun. This relocation allows the solar system as a whole to be observed in motion. This program can be very useful as a demonstration device for homework or as a laboratory exercise. It (and programs like it) will gradually supplant many special-purpose programs that were written for slower computers and showed only a single aspect of motion on the celestial sphere (such as retrograde motion).

Retrograde motion is one of the most important planetary motion phenomena to explain. Texts usually illustrate it with a cryptic diagram that shows the orbits of two planets and a retrograde loop drawn in the sky with numbered lines joining various planetary positions as projected onto the sky. A much more effective way to demonstrate this phenomenon is to show a simulation of a planet executing a retrograde loop on the computer screen using a program like Voyager or one written just for this purpose (Johnson, 1984a). Ptolemy's system of epicycles for explaining retrograde motion can also be demonstrated on the computer. In fact, a very effective demonstration is to plot the actual motion of the planets from a geocentric view (Schwartz, 1983). This plotting allows the idea of epicycles, which were first used to explain the phenomenon, to be tied to the actual phenomenon. As well, the Copernican view may be shown in an demonstration in which one planet overtakes another. The line of sight connecting the two planets can be drawn and will show the back and forth motion of the retrograde loop (Johnson, 1984a).

There are other examples. The apparent motion of the sun as a function of season and latitude can be demonstrated very effectively with the computer. A horizon view that shows the rising or setting sun demonstrates that both the position of sunrise and sunset and the angle of the sun's path with respect to the horizon change with the season (Sumners, 1983a). While a view showing the entire visible hemisphere is impossible to show due to the limited resolution of the computer screen, it is possible to show various sections of this hemisphere and the motion of the sun through them. Thus, the diurnal motion of the sun may be shown in three plots representing the eastern, southern (for observers in the northern hemisphere), and western horizons (MECC, 1985). Lunar phases may be demonstrated by programs that animate the motion of the moon around the Earth and simultaneously show the appearance of the moon as seen from Earth (Sumners, 1983b). There are several ways in which the computer may be useful in discussing eclipses. For solar eclipses, a map of a portion of the Earth may be drawn on the screen with the shadow of the moon moving across it (Parker, 1988). A diagram showing the parts of a shadow can also be drawn. One interesting program shows the positions of the Earth, moon, and sun, and the lines of nodes of the moon's orbit schematically. This program will indicate the possibility of lunar or solar eclipses when the new or full phase is coincident with the moon being at one of the nodes of its orbit. Again, care must be taken in using these programs since the drawings cannot be made to the proper scale (Zink, 1983a).

The computer makes the job of describing Kepler's Laws much easier. To start with, we no longer have to try to sketch ellipses. We can present a plot either as a whole or piece by piece. First the ellipse is drawn, then the semi-major axis is drawn and labelled, and finally the foci are drawn and labelled (Johnson, 1984b; Zink, 1983b). The first law is illustrated by a body moving in an elliptical orbit, its speed varying according to its distance from the focus. But the splendor of the computer emerges with the discussion of Kepler's Second Law. How often have you tried to describe the meaning of equal areas in equal times? Using a computer, we can plot the radius vector and color in sectors of equal areas as we go (Johnson, 1984b; Seeds, 1985). We can use orbits of different semi-major axes to demonstrate the third law. In this case, there may be several objects on the screen moving in orbits of different semi-major axes with periods given by Kepler's Third Law. Finally, bodies with orbits of various semi-major axes, eccentricities, and orientations can also be shown (Zink, 1983b).

A very good simulation allows the student to investigate Newton's Laws of motion. Objects can be moved on the Earth under varying conditions of friction or in space with or without a gravitational field. One exercise lets students move an object around a track under various conditions. The goal is for the student to apply forces in such a way as to have the object go around the track without colliding with one of the sides (Schwartz, 1985).

A simulation that might serve as a programming project for advanced students and one of the earliest applications of computers in physics is to solve for the motion of three or more bodies interacting gravitationally (Cromer, 1981; Bork, 1981). This simulation differs from the Kepler's Laws simulations since the computer calculates motion in real time while in the former case the results were presented based on calculations previously made and stored as data. With the more modern computers, these calculations can be done rapidly enough to allow the results to be displayed as the calculation proceeds. A good example of this type is Gravitation, Ltd. (Rommereide, 1988). This program allows several bodies to be set in motion simultaneously and the effects of their mutual gravitational interaction to be observed.

A number of interesting simulations treat various aspects of space travel in the solar system. These range from one in which the student has to choose proper positions in the orbit of the Earth and Mars to launch a probe in a least-energy ellipse (Simon, 1984a) to a much more complicated one in which the student has to get a space probe to Saturn and achieve an orbit inside the inner ring (Huntress, 1982).

Stellar Astronomy

Much of an introductory astronomy course is concerned with the properties of stars and the means by which we know these properties. These include the absorption and emission of radiation by atoms, the formation of spectral lines, spectral classification, parallax, proper motion, binary-star motion, the H-R diagram, calculation of stellar models, and stellar evolution.

There are several programs that treat the emission and absorption of radiation by atoms. Some work using the Bohr-atom approach (Johnson, 1984c), while others use energy-level diagrams. In either case, a photon is shown approaching the energy levels of an atom. When the photon reaches the atom, it disappears and the electron in the atom moves up one or more levels. A similar representation of photon emission is also possible.

An impressive program is available that teaches some of the basic principles used in classifying spectra (Simon, 1984b). Students compare an unknown spectrum with two standard spectra. They then give a classification for the unknown spectrum. If this classification is incorrect, they choose two new spectra and try again. Though this program has been criticized by some astronomers since the representations of spectrum drawn on the computer screen (due to limited resolution) do not effectively resemble the appearance of a photographic spectrum of the same type, I do not agree. A non-science student should learn how science functions and not specific details from an introductory science course. Therefore, any exercise that teaches some of the methodology of spectral classification is worthwhile.

Parallax is another area in which computer simulations are valuable aids for student visualization. These should be used to supplement more traditional demonstrations involving, for example, outstretched fingers. In one program, the computer screen show the Earth's motion around the sun with a line from the Earth to a nearby star (Zink, 1983c, A'Hearn *et al.*, 1988). At the same time, another view shows the apparent motion of the star with respect to the background star field. Additionally, the distance of the star from the Earth may be varied and the resulting variation in parallactic shift observed.

Stellar proper motion is a fascinating topic for computer simulations (Dukes and Roskoske, 1979). Constellation patterns are plotted on the screen and allowed to evolve with time using extrapolations of the best current values of the proper motion. Students are especially fascinated when the time span is long enough that the pattern we observe today completely disappears. Of course, the warning must be given that the measured proper motions are imprecise enough that these long extrapolations are not valid. However, students can use such plots to discover moving groups such as the Hyades or those members of the Big Dipper that are part of the Ursa Major moving group.

One of the best uses I have found for the computer is in describing the motion of binary-stars systems. One program useful for this purpose plots the motion of two bodies around a common center of mass as seen from above the orbital plane (Seeds, 1985b). The eccentricity of the orbits is varied as well as the mass ratio of the bodies. A program like this is very effective in demonstrating the positions of the two bodies and the center of mass at various points in the orbit. Another class of programs involves plotting the motion of two stars as seen from the orbital plane. These programs demonstrate the properties of eclipsing systems. Two stars are shown in a magnified view. The motion can be referred to the center of mass of the system or to the center of the primary star. The light and velocity curves of the system can be plotted as a function of orbital phase. I use two such programs. The first is definitely a demonstration program (Zink, 1983d). It shows two views of a binary system: one from the orbital plane and the other from the pole. The two stars move as long as is necessary for students to comprehend the plots. Next, the planar view is plotted along with a light and velocity curve. The second program is similar except here the student can exercise control over the properties of these stars and the inclination of the orbit, making it useful as a laboratory or homework exercise (Reitmeyer, 1980).

The H-R diagram is one of the most valuable tools of the astronomer. Certainly, we spend considerable time discussing it. One very good program lets us quickly plot an H-R diagram with various groups of stars (Alexander, Foster, and Unruh, 1983a). I realize that similar plots can be drawn on the board (slow and messy) or projected from slides (not flexible). With the computer, we can vary the plots as class discussion progresses. For example, we can first plot an H-R diagram showing a main-sequence line. Next we can add plots of the nearest stars, the apparently brightest stars, or both, or we can plot a series of cluster isochrons and add stars from star clusters such as the Pleiades or Hyades, demonstrating how the series enables us to date star clusters. Additionally, we can take one star and watch the change in position on the H-R diagram over time. In another program, one of the most effective uses of the computer I have seen, we can take a star cluster and watch how the position of the stars change on the H-R diagram as the cluster ages (Simon, 1984c). With this, we see that massive stars evolve the fastest and move off the main sequence long before the lowest mass stars reach it.

At least two programs enable simple stellar models to be presented to a class (Hall, 1977; Simon, 1984d). Graphically, these programs plot variations in properties such as density and temperature with distance from the center of the star. While neither is correct in all details, at least one of them calculates a crude set of models. The surface properties of these models can be used to infer the presence of a main sequence and a mass-luminosity law.

An area that is peripherally treated in astronomy courses, but which has great fascination for the average student, is the possibility of interstellar travel. Some of the problems associated with the relativistic effects of interstellar travel are treated in one computer simulation (Simon, 1984e). The student controls an interstellar ship on a journey from one stellar system to another by varying the acceleration of the ship. The computer calculates and displays the relativistic time dilation and length contraction effects involved. The student must decide when to start slowing the ship in order to arrive at the destination at zero relative speed. The main result of using this simulation is to illustrate that relativity and common sense have little in common.

Moving from properties of individual stars to groups of stars, relatively few programs are available. One shows the differential rotation of the galaxy (Thomas and Grayzeck, 1983). With an animation, students much more easily see the effects of this type of rotation. Several objects at different distances from the center move around the center at differing speeds. A more recent program (Dykla, 1988) simulates the gravitational interaction of a star cluster. In this simulation, a number of stars move under the influence of their mutual gravitational attraction. Additionally, the effects of a background of dark matter may be included.

The only simulations that have been prepared involving systems outside our own galaxy have dealt with the Hubble law. These can be divided into two classes. The first is similar to the rubber band or rubber balloon analogy. A number of points are plotted on the computer screen and moved such that their separations obey the Hubble law (Johnson, 1984d). The second class plots graphical representations of the Hubble law. A very good program, but one that is too complex for the average introductory astronomy student in this country, plots the Hubble law and shows its evolution with time illustrating that early in the history of the universe the slope was steeper than at the present (Alexander, Foster, and Unruh, 1983b).

An excellent use of the computer allows students to assimilate the knowledge they have gained from a number of different areas to construct varied planets circling different stars. There are several such programs available though they are, of course, based on rather speculative science. Some of them postulate the existence of alien species with certain characteristics, requiring the student to construct a world habitable by these species (Simon, 1984f; O'Brien and Roney, 1987).

3. The Indoor Telescope

An unusual mode of computer use we have had under development at the College of Charleston for the past five years involves what we call an indoor telescope. We recognized a number of years ago that astronomy laboratories are different from chemistry and physics laboratories in that students generally do not gather quantitative data. Rather, they analyze data gathered by others or make qualitative observations of astronomical phenomena. The reasons for this difference include the fact that obtaining quantitative astronomical data requires much more sophisticated equipment than that required for physics and chemistry. We recognized that one way of circumventing this problem was to use the microcomputer as a simulated research telescope to enable students to gather and analyze quantitative data. Each student is provided with a simulated universe of 1000 stars. The properties of these stars are calculated based on general luminosity function with the assumption of a limiting magnitude of 11. This data set contains variable stars of various types as well as high-proper-motion stars and an open star cluster. In addition, interstellar reddening is present. Each student has his or her own diskette with individualized data. The object of the simulation is for the students to find out as much as possible about the 1000 stars in their data set. With their simulated telescope, students can measure positions and magnitudes as well as obtain spectra.

In interacting with the program, the student first requests one or more nights of telescope time. Once this is accomplished, they choose whether they wish to obtain photographs, Cassegrain spectra, objective prism spectra, or photoelectric measurements. When the observing session begins, students are presented with a view of a small portion of their star field. They move the telescope to the position at which they want to take data and obtain it. A simulated clock keeps track of the progress of the night and forces observations to cease at sunrise. Once the student has obtained one or more photographs, the data can be analyzed. To do this he or she uses a simulated blink comparator. Two plates at a time are loaded and just as in a real blink comparator, they are intercompared. Choosing plates obtained with different filters enables detection of either very blue or very red stars. Choosing plates obtained at different times allows detection of variability or proper motion. In order to detect proper motion, the existence of a first generation set of plates taken a number of years earlier is postulated. Loading a current plate with one of these older plates usually reveals one or more stars with a detectable proper motion on each plate. Our simulated comparator includes a built-in measuring engine and iris photometer so that positions and magnitudes of stars may be measured. From the measurements, students can determine proper motions easily and distances with difficulty. In the latter case, they must remove the effects of interstellar reddening to get a true apparent magnitude and obtain the absolute magnitude from either the unreddened colors or the spectral type. When a student finds a variable star, he or she can determine the period of variation and use information such as the spectral type to determine the type of variable.

After students have obtained and analyzed the data, they can draw conclusions about the properties of their stars and report them to the computer, which judges the validity of their work and awards them appropriate points. Types of conclusions that may be reported include the colors and spectral types of stars, their distances, and the periods of variable stars.

4. Equipment Required

Many instructors are hesitant to attempt to incorporate computers into their curriculum because of the difficulty of obtaining funds to equip a computer laboratory. From the above discussion, you have realized that one of the best ways to use the computer in teaching is as a demonstration device. For this purpose, one computer is sufficient for an entire class. Ideally, there should be a means of projecting a large image of the computer screen. However, I have worked for a number of years with 2 small monitors for a class of 60 students. While the students can't see what is written on the computer screen, they can see the graphics. Since these are the essence of most computer simulations, this equipment is sufficient. However, a better means is to connect the computer to a projection device such as a projection television or a liquid crystal display that fits onto an overhead projector. If you want students to interact directly with the computer, then a computer lab is necessary. A minimal lab is one computer available 8 hours per day for every 30 students. This could be used for take-home labs or homework exercises. In a formal lab, the best situation is one computer for every two students. We run with one for every four students. Many times this still requires take-home labs.

5. Problems Involved in Teaching with Computers

I do not want to leave the impression that computers are a cure-all for the problems facing astronomy education or that their integration into the curriculum is easy. A number of difficulties are present. First, a wide variety of computers are available, many of which are incompatible with each other. Obviously, the hardware you have will limit the programs you can use. Since to date in this country, the most popular hardware configuration for educational use has been the Apple II series, the widest variety of software is available for this machine. However, IBM-compatible computers and the Apple Macintosh are becoming more prevalent (especially at the post-secondary level) and so more software is being developed for these machines. Another problem concerns the setup time required to use computers as demonstration devices. Unless permanent projection TV or monitors are installed in the classroom with provisions for easy attachment of a computer, setup could require as much as 20 minutes per class. Even with matching hardware and software and a good projection setup, other problems remain. For example, a number of software programs that are not equivalent treat the some topic. In the discussion of Kepler's Laws above, I referred to several programs by different authors. Since I like to use pieces of each of these programs, time is required to switch from one program to another. It would be much better if I were able to put together my own selection of pieces from each. Unfortunately, this is not currently possible. Student motivation is also a problem. No matter how interesting the software is to the instructor, the student is unlikely to be equally interested. It is not sufficient to tell a student to run a particular program to find out what he or she can from it. Guidance is needed to ensure that students use the program properly and some method of evaluation is required.

It might be asked why many of the programs described are relatively old, dating from the early eighties. Unfortunately, the educational market in astronomy is not a popular one for software developers. The development of the bulk of astronomy software is driven by the market among amateur astronomers. This is the main market for the planetarium-type programs mentioned earlier. Except for these programs, all of the programs discussed have been developed by astronomy educators for use in education. The time required for such a person to develop a program for a new machine seems to be about five years. Thus only now are we seeing programs developed by educators begin to appear for the Macintosh and more recent IBM compatible machines. Another factor is the relatively low level of funding for educational developments available in the United States in the last few years. Recently we have seen an increase in such funding from both Federal and private sources. In addition to the project by A'Hearn *et al.* mentioned earlier, Shapiro and Sadler (1987) have described the preliminary software development being carried out with N.S.F. funding by the staff of Project STAR. I am hopeful, therefore, that there will soon be similar but more sophisticated material than that described above available.

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References

Note: There is no accepted system for providing references to computer software. In some cases authors are uncertain or unknown. I have adopted the convention of using embedded text references giving the author or in a few cases the publisher of the software. If a program has been discussed in the astronomical literature, I have cited that reference. Disks consisting of collections of software have been treated as books with individual programs as journal articles. The availability of many of these programs is uncertain. Where possible I have given an address for information.

A'Hearn, M.F., Bell, R.A., Blitz, L., Freedman, I., Greenblatt, J., McDaniell, C., Ohlmacher, J.T., and Trasco, J.D., 1988, "Parallax Lab" part of *Introductory Astronomy Minilabs for Non-Science Majors* (College Park, MD: Astronomy Program and Instructional Computing Division, University of Maryland).

Alexander, D., Foster, D., Unruh, H., 1983a, "H-R Diagrams" on *Modern Astronomy Demonstrations* (New York: John Wiley and Sons).

Bork, A., 1981, *Introductory Mechanics* (Iowa City, IA Conduit).

Cromer, A., 1981, *Three Body Orbits* (Newton Centre, MA: EduTech, 634 Commonwealth Avenue, Newton Centre, MA 02159).

Dukes, R., Jr., and Roskoske, T., "An Interactive Computer Exercise for Elementary Astronomy," *AAPT Announcer* **9(2)**, 79, 1979.

Dykla, John J., 1988, "Star Cluster Dynamics Simulation with Dark Matter," presented at The Conference on Computers in Physics Instruction, Raleigh, NC.

Hall, D.E., 1976, "A Stellar-Structure Model for the Classroom," *B.A.A.S.*, **8**, 546.

Huntress, W., 1982, *Saturn Navigator* (Sub-Logic, 713 Edgebrook Drive, Champaign, IL 61820).

Johnson, K.H., 1984c, "The Bohr Atom" on *Astro-Demos*, (Reno, NV: Fleischmann Atmospherium/Planetarium; privately distributed).

Johnson, K.H., 1984d, "Hubble Law" on *Astro-Demos.*

Johnson, K.H., 1984b, "Kepler's Laws" on *Astro-Demos.*

Johnson, K.H., 1984a, "Retrograde Motion" on *Astro-Demos.*

Kanipe, J., Korchmal, M., Paul, L., Berry, R., Bailey, J., 1988, "Personal Planetariums: The Night Sky in Your Computer," *Astronomy*, **16(8)**, pp. 36–41.

Mathis, T., 1988, *Voyager* (Carina Software, 830 Williams Street, San Leandro, CA 94577).

MECC, 1985, *Sky Lab* (St. Paul, MN: Minnesota Educational Computing Consortium).

Mosley, J.E., "Software for Classrooms," *Journal of Computers in Mathematics and Science Teaching* **VI(1)**, pp. 69–70.

Mosley, J.E., "Astronomy on an Apple Macintosh," *Journal of Computers in Mathematics and Science Teaching* **VI(3)**, pp. 55–57.

Mosley, J.E., 1988a, private communication.

Mosley, J.E., 1988b, "Review Corner," *Sky and Telescope*, **76**, 676.

Mosley, J.E., and Fraknoi, A., 1986, "Computer Software for Astronomy," *Mercury*, **XV**, 152.

Reitmeyer, L., 1979, "Demonstration of a Microprocessor Program of Binary Stars for General Science Instruction," *AAPT Announcer*, **9(2)**, 81.

O'Brien, T.C., III, and Roney, M.L., *Planetary Construction Set* (Sunburst Communications, 39 Washington Avenue, Pleasantville, NY 10570-9971).

Parker, R., 1988, *Visible Universe* (Parsec Software, 1949 Blair Loop Road, Danville, VA 24541).

PicoSCIENCE, 1988, *Superstar* (41512 Chandbourne Dr., Fremont, CA 94539).

Schwartz, J.L., 1983, "The Four Inner Planets" on *Microcomputer Software for Undergraduate Physics* (New York: Addison Wesley).

Schwartz, J.L., 1985, *Sir Isaac Newton's Games*, (Sunburst Communications, 39 Washington Avenue, Pleasantville, NY 10570-9971).

Seeds, M., 1985, "Orbital Motion" on *Horizons: Exploring the Universe* (Belmont, CA: Wadsworth).

Shapiro, Irwin I., and Sadler, Philip, 1987, "Project STAR Annual Report to the National Science Foundation Washington, D.C.," (Cambridge, MA: Harvard College Observatory).

Simon, S., 1984a, "Expedition to Mars" on *The Astronomy Disk* (Englewood Cliffs, NJ: Prentice-Hall).

Simon, S., 1984b, "Spectral Classification" on *The Astronomy Disk.*

Simon, S., 1984c, "Stellar Evolution" on *The Astronomy Disk.*

Simon, S., 1984d, "Stellar Model" on *The Astronomy Disk.*

Simon, S., 1984e, "Starship" on *The Astronomy Disk.*

Simon, S., 1984f, "Build-a-World" on *The Astronomy Disk.*

Sumners, C., 1983a, "Sunrise/Sunset/Sun Locator" on *Astrografix* (Houston, TX: The Astronomy Data Center, Houston Museum of Science; privately distributed).

Sumners, C., 1983b, "Moon Plotter for Phases/Locations" on *Astrografix.*

Thomas, P., and E.J. Grayzeck, 1983, *B.A.A.S.*, **15**, 996, 1983.

Zink, J., 1983a, "Lunar Phases and Eclipses" on *Astronomy Demonstrations* (University Park, PA: Department of Astronomy, Pennsylvania State University; privately distributed).

Zink, J., 1983b, "Kepler's Three Laws of Planetary Motion" on *Astronomy Demonstrations.*

Zink, J., 1983c, "Parallax" on *Astronomy Demonstrations.*

Zink, J., 1983d, "Binary Stars" on *Astronomy Demonstrations.*

Discussion

T.J. Balonek: *In addition to using microcomputers as demonstration devices, it is desirable to expose introductory college-course students to how scientists use computers in their research. Since astronomy is the only physical science and/or laboratory course that many college students take, these exercises should also be representative of how computers are used in other sciences. One such example is to develop laboratory exercises that use inexpensive microcomputers to perform image processing of astronomical images, in which students learn the problem-solving techniques and thought processes used in image analysis.*

B.W. Jones: *Microcomputers can also be used in an adaptive mode with frequent branching to meet individual students needs at a variety of points in the program. This applies as much to astronomy programs as to programs in other subject areas.*

G.S. Mumford: *What is the availability of the software you have discussed?*

R.J. Dukes, Jr.: Demonstration programs are available from many sources. Prentice-Hall, Wiley, and Wadsworth have packages available for sale or to adopters of their textbooks. A list of available astronomy software is available from the Astronomical Society of the Pacific. The American Association of Physics Teachers publishes descriptions of public domain software in their quarterly *Announcer.* The Physics Coursework Project at North Carolina (Raleigh, North Carolina, U.S.A.) State University maintains a collection of public-domain physics software as well as a list and review of commercial software. Some of these programs are suitable for astronomy. The *Physics Teacher* publishes software reviews. The *Planetarian* likewise. *Sky & Telescope* and *Astronomy* publish monthly columns that consist of program listings and/or reviews. I will be happy to send a list of my personal recommendations to anyone writing me. I can also provide some Apple programs that I have written if a floppy disk is enclosed. I am maintaining a list of people interested in using *Indoor Telescope.* I will notify these people of its availability when it is in a form suitable for distribution.