A KELLERIZED COURSE IN INTRODUCTORY ASTRONOMY FOR LIBERAL ARTS MAJORS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

JOHN ROBERT POND

1973

ABSTRACT

A KELLERIZED COURSE IN INTRODUCTORY ASTRONOMY FOR LIBERAL ARTS MAJORS

By

John Robert Pond

The problem considered in this thesis is the development of an introductory course in astronomy for non-science majors at the U.S. Air Force Academy.

After a review of the current available literature, it was decided to: adopt the Keller method of instruction; present a conceptual approach to the subject; utilize visual aids to a large extent with the planetarium being the focus for this visual emphasis; include supplementary information in the form of additional readings, motion pictures, and planetarium programs.

The textbook is _Astronomy: Fundamentals and Frontiers_, by Robert Jastrow and Malcolm Thompson. This material is presented in an 18-unit, one-semester course with notes to the instructor and a section for reference material. The reference material includes books, articles, films, and sources of other Kellerized courses.

A KELLERIZED COURSE IN INTRODUCTORY ASTRONOMY FOR LIBERAL ARTS MAJORS

By

John Robert Pond

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

College of Natural Science

1973

John R. Pond

ACKNOWLEDGMENTS

G92907

I would like to acknowledge the efforts of those who helped to make this thesis a success. First of all, thank-you to my wife Betsy, whose moral support and typing were both invaluable. Next, thank-you Mr. Von Del Chamberlain for help in locating much of the source material and for help on planetarium-related subjects. Thirdly, thank-you Dr. Thomas R. Stoeckley for your help as the head of my thesis committee. Finally, thank-you Dr. J. Robert Brandou for your support throughout the past year as well as for being a member of my thesis committee.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

The problem considered in this thesis is the development of a course in astronomy. The course is designed for cadets at the U.S. Air Force Academy to be taken as an elective activity. The material also could be used as an introductory course for any liberal arts majors at the university level.

The course is proposed in conjunction with the author's future duties at the Air Force Academy. These duties include teaching an introductory astronomy course as part of an instructional team. Each instructor will have a small section of 12-15 students for which he is the primary teacher. The facilities available include a 10-inch reflecting telescope, and numerous smaller refracting telescopes. Moreover, an excellent planetarium is available at the Academy and offers opportunity for further educational benefits.

R. E. Berendzen of Boston University emphasizes the necessity for such an endeavor. "[College] enrollments in astronomy courses for science majors are diminutive, those for non-science majors are sizable--indeed, often enormous. In the decade 1955-1965 non-science enrollments in astronomy nearly doubled."[1] George Abell of the education committee of the American Astronomical Society said that with growing enrollment and with astronomical research budgets becoming smaller, his group has switched from an emphasis on "improving general astronomy education" to promoting "aspects of the science for nonspecialists."[2] It appears that more people must become acquainted with astronomy on a broad scale. An introductory course of a conceptual nature seems most likely to contribute to this program.

Throughout the author's academic and professional career, the predominant instructional method has been a lecture-test procedure. Students attend lectures and take tests. A personal approach was not evident in the instructor and the interest or motivation of the students was dependent on the instructor's enthusiasm and ability. Too often it seems, the interest of the instructor is elsewhere than in the classroom and, consequently, so is the interest of the students. Attendance, if voluntary, drops as the term proceeds. If attendance is required, the result is just a room full of uninterested students.

The author was introduced to the Keller method while taking a physics course at Michigan State University in the fall of 1972. It was decided that existing Kellerized courses in astronomy would be studied to determine if they were suitable to the needs of the Air Force Academy. In addition, were they presented in a conceptual manner, compatible with a one-semester course for non-science majors, and were there suitable textbooks or study materials?

Likewise, were there sufficient outside readings available for interested students? Moreover, were the textbooks on a level that was compatible with liberal arts majors? Was there a definite attempt to relate to non-science minds?

After examining the available Kellerized courses, a search for specific source material was necessary for the new course. The author's plan was to survey current textbooks to determine their applicability. If none were suitable, then other sources would have to be utilized. The possibilities included writing a completely new manuscript for the desirable material, or gathering articles from magazines or pamphlets, or chapters from available textbooks to present to the students.

Astronomy, by its nature, places a great deal of emphasis on the observation. Two methods of providing this visual aspect are available: utilize the planetarium to the maximum extent, and conduct actual outdoor observing sessions. Well-planned and presented planetarium programs could be used as motivational tools. Such programs can be used to relate non-scientific disciplines to the science field, a vital aspect of this type of course.

Furthermore, there are going to be students who will seek knowledge beyond that presented in a syllabus. This knowledge can take two forms. The first could be purely scientific information in addition to that which is available in the textbook. Moreover, a liberal arts student, in particular, may want to experience some correlation between his non-scientific interests and the rudiments of science, specifically the science of astronomy. Both of these forms can be dealt with by carefully choosing pertinent outside reading.

As has been outlined, the problem is to develop an introductory astronomy course for liberal arts majors using the Keller method of instruction. In addition, a secondary problem is the selection of a textbook and motivational material in the form of supplementary information. The second chapter will deal with the examination of available literature on the subject with analysis and comments. The final chapter will list the conclusions drawn from the research along with the course outline.

The specific nature of the task requires the full development of a practical course guide for the prospective students, with instructor's notes, narratives for planetarium presentations, lists of films, and bibliographic data on all selected references. The completed course materials are included in the appendices.

---

[1] Richard E. Berendzen, "On the Career Development and Education of Astronomers in the United States" (unpublished Ph.D. dissertation, Harvard University, 1968), p. 245.

[2] Steven A. Africk, "Where Is Astronomy Education Headed?" Sky and Telescope, XLII (November, 1971), 277.

CHAPTER II

A REVIEW OF LITERATURE

The first item considered was the survey of current Kellerized astronomy courses. Since this course would be limited to non-science majors, the survey was confined to those courses designed with this audience in mind. The December, 1972, issue of the Astronomy Education Newsletter listed sources of Kellerized course materials. These materials were obtained. Along with the request for these materials, a further request was made for information on any other Kellerized courses for non-science majors. Those who replied listed the above newsletter as the only known source at the time. These courses are listed in Appendix B under "Reference Material--Part III."

In general, all the courses surveyed held closely to the Kellerized format. Each was organized in the traditional manner with a historical beginning. The solar system and its part in the birth of astronomy were always the first topics considered. From there the courses progressed further into the universe to eventually encompass cosmology.

The approach to the Keller idea used in each course was somewhat different. Dr. Leidecker of American University had students listen to "mini-lectures" by other students to determine mastery of the individual units. He then gave a written examination after about four units. There were no observing sessions, films, or planetarium programs.

Dr. Six of Western Kentucky used an occasional film loop and transparencies as "resource materials." His course is restricted to the solar system and is designed for an 11-week quarter. Again a planetarium is not mentioned. He did, however, cite additional readings as supplementary information.

Dr. Dessler of Rice University compiled quite a detailed syllabus for a one-quarter course on the solar system. He also used the mini-lecture for determining proficiency, but included a written exercise with each unit. This appears to be an excellent check of mastery of the material. He also included laboratory exercises. However, no telescopic observing sessions, films, or planetarium programs were utilized. In addition, he included a considerable amount of mathematics, even some calculus.

Dr. Schroeder of Oklahoma State designed a course for one semester. He also used film loops and slides to some extent. The majority of the course, however, was spent on the solar system with little about the other and more significant topics in the universe. Only 40 percent of the course covered topics outside the solar system. Again no use of a planetarium was evident.

Finally, Dr. Jeffreys of the University of Texas at Austin stressed the mini-lecture method of evaluation like Dessler and Leidecker. Moreover, he used written and oral examinations for each unit like Dessler. At times throughout the course he scheduled optional lectures and films. His units included 75 percent reading and 25 percent laboratory. No planetarium shows were used, and no outside reading was suggested.

Note that none of these courses stressed the visual or conceptual aspects of astronomy. The planetarium was not utilized in any of the courses. Some used films and slide shows, but not to any extent. Only Dr. Six made supplementary readings available.

The textbooks used by each of these instructors along with other general texts will be examined in the next portion of this chapter.

Abell said that "[students should learn] something about the general descriptive nature of the universe in which we live and more fundamentally, how astronomers get the information they obtain."[1] In 1966, a study by M. B. Strobe compared a factual method of teaching introductory astronomy with the conceptual method. One major result was that the conceptual group showed a stronger interest in taking additional science courses.[2] The same study also showed that the ability of a group to learn concepts is dependent on the method of presentation.[3] With these thoughts in mind, a survey of textbooks was made. The major criteria would include the following: the book would be conceptual in presentation, and should view the universe as a whole with the solar system being relegated to its rightful insignificant place. Fortunately a textbook published in 1972 appeared to fit these criteria closely. It is by Robert Jastrow and Malcolm Thompson and is named Astronomy: Fundamentals and Frontiers. The other textbooks[4] surveyed, including the ones used in the Kellerized courses already discussed, although well written, were found to be of the traditional historical approach and very much dependent on mathematics. It is the author's opinion that these other texts could be used as reference material for interested students. However, in order to foster interest and motivation in astronomy among liberal arts majors, Jastrow's textbook was found to be superior.

Possibly one of the reasons why the planetarium was not extensively used in the above surveyed introductory courses, was because of non-availability. Berendzen found that "campus planetariums are not widely available. Of 47 leading universities in 1966, 30 had no planetarium."[5]

The author could locate no studies done on the effectiveness of a planetarium in education at the college level. There were studies done, however, on the effectiveness of a planetarium on elementary school students. Smith, in 1966, found classroom instruction superior to planetarium instruction in sixth grade classes in astronomical concepts.[6] He did conclude, however, that this "may be attributed to a more familiar learning situation existing in the classroom."[7] Rosemergy found similar results in 1967.[8] Nevertheless, the author found in informal interviews conducted with members of a course called "Sky Interpretation" which utilized the planetarium, that in no case were students disappointed with the part of the course which employed the planetarium. Furthermore, most felt motivated to seek further knowledge of astronomy because of their brief contact through the planetarium. These were students majoring in the Environmental Interpretation option of the Parks and Recreational Resources Department of Michigan State University. In addition, professionally presented public programs in planetariums can serve as motivators as well. This is evidenced by the large groups attending the public programs at Abrams Planetarium of Michigan State. During the year ending July 1, 1973, 43,520 people attended public programs there.[9] Admittedly, these are geared for entertainment, but they are based primarily on astronomy topics. Consequently, if students can feel entertained while engaged in learning, the situation approaches the ideal. Of course, the planetarium, since it is capable of handling multi-media programs, can be utilized for films and slide presentations as well.

The next item to be considered was the supplementary readings. Citing personal experience and the few readings suggested in the aforementioned Kellerized courses, it was decided to survey the last ten years' issues of _Scientific American_, _Sky and Telescope_, and _National Geographic_. The treatments of astronomy by _National Geographic_, although limited in number, were found to be the most easily read and understood. _Scientific American_ articles were well written and most always conceptual. In addition, a non-science oriented reader could understand most of them.

Sky and Telescope, a magazine devoted to amateur astronomy, also offers many applicable articles.

Over 450 articles were examined and specific selections for each of the 18 units of the course are cited with the course materials in Appendix B.

Finally, the film catalogs of six large universities were surveyed for applicable films. The descriptions of some 200 films were considered. Recommendations were made for showing with particular units. In addition, Appendix B lists further applicable films.

---

[1]George O. Abell, "And Now, May I Wish You All a Very Good Morning," The Planetarian, I (September 21, 1972), 37.

[2]Marvin B. Strobe, "A Comparison of Factual and Conceptual Teaching in Introductory College Astronomy" (unpublished Ph.D. dissertation, Utah State University, 1966), p. 73.

[3]Ibid., p. 75.

[4]The textbooks surveyed (written by Abell(2); Asimov; Birney; Hynek and Apfel; Menzel, Whipple, and de Vaucoulerus; Motz and Duveen; and Payne-Gaposchkin and Haramundanis) are listed in the bibliography.

[5]Berendzen, op. cit., p. 577.

[6]Billy A. Smith, "An Experimental Comparison of Two Techniques (Planetarium Lecture-Demonstration and Classroom Lecture-Demonstration) of Teaching Selected Astronomical Concepts of Sixth Grade Students" (unpublished Ed.D. dissertation, Arizona State University, 1966), p. 47.

[7]Ibid., p. 47.

[8]John C. Rosemergy, "An Experimental Study of the Effectiveness of a Planetarium in Teaching Selected Astronomical Phenomena to Sixth Grade Children" (unpublished Ph.D. dissertation, University of Michigan, 1967), p. 87.

[9]Abrams Planetarium Annual Report, 1972-73; Submitted to the Associate Director, Continuing Education Services, Michigan State University, p. 3.

CHAPTER III

CONCLUSIONS

After having decided that there exists a problem, determining a definite need for the study, and examining the available alternatives, this thesis is advanced.

Conclusions Regarding the Proposed Course

1. This will be an introductory course in astronomy for liberal arts majors. It will be conceptual in nature and will include planetarium programs and actual outdoor observing sessions.

2. The course will be organized using the Keller plan.

3. Supplementary information will be used as a motivational and explanatory tool only and no examination questions will be taken from this information. The supplementary information in several instances and part of the introduction seek to relate significant non-scientific ideas with scientific discoveries. Furthermore, the scientific method is related to non-scientific activities.

4. The use of visual aids will be stressed as much as possible. Motion pictures applicable to a given unit will be shown in the planetarium during the regularly scheduled class periods. An evening observing session is

planned early in the course in order to foster early motivation. In addition, instructors will be available for additional evening or early-morning observing sessions if interest is sufficient. These sessions will be encouraged throughout the course. The planetarium will be used as a further motivational aid. There are three specified times during the course that planetarium use is recommended. These three programs are in addition to the film showings which will be accompanied by current sky presentations.

5. The textbook for the course will be Astronomy: Fundamentals and Frontiers, by Robert Jastrow and Malcolm Thompson. It is written specifically for liberal arts majors and in conceptual form. Moreover, the textbook is organized with the solar system coming last. This is consistent with the view that our solar system plays a rather insignificant role in the universe. Although this is a reversal of the traditional approach as well as the historical sequence of discovery, it does present the universe in a manner which allows a better overall perspective. The universe is examined as a whole in which the solar system is only a part, a view that is more consistent with reality. The text divides neatly into 18 units which correspond to an 18-week semester course. In addition, it offers thought-provoking end-of-chapter questions that stimulate conceptual ideas.

6. Each of the 18 units will have a reading assignment from the text along with suggested study questions.

Listed with each unit are a group of learning objectives and a list of important terms for that unit. In addition, each unit will contain written supplementary information, suggested additional reading, and/or planetarium programs and observing sessions.

7. Table 1 contains a course outline with unit titles:

Table 1.--Course outline.

Unit I	Introduction
Unit II	The Changing Night Sky and Contents of the Universe
Unit III	The Nature of Light
Unit IV	Tools of the Astronomer
Unit V	The Message of Starlight
Unit VI	The Hertzsprung-Russell Diagram
Unit VII	Nuclear Energy Sources
Unit VIII	Stellar Evolution
Unit IX	The Milky-Way Galaxy
Unit X	Galaxies
Unit XI	Radio Galaxies, Seyfert Galaxies, and Quasars
Unit XII	Cosmology
Unit XIII	The Solar System
Unit XIV	The Earth
Unit XV	The Moon
Unit XVI	Venus, Mars, and Jupiter
Unit XVII	The Earth and Venus, A Study in Contrast
Unit XVIII	Life in the Cosmos

The course as described in Appendix B will be proposed for implementation in January, 1974, at the U.S. Air Force Academy. Data will be collected regarding its effectiveness.

Further Suggestions for Research

1. A study to determine the effectiveness of the planetarium in teaching specific astronomical concepts to non-science majors.

2. A study to compare the effectiveness of this Kellerized conceptual approach to astronomy with other Kellerized courses or lecture-test courses. A specific item to study may include the number of non-science majors who are motivated to enroll in further science courses.

3. A study to determine the effectiveness of a planetarium in aiding the motivation of students to take further science courses.

The author has endeavored to present a course in introductory astronomy that will be useful and effective, both to the author and to other interested parties. It is hoped that students taking this course find the motivation for astronomy that will encourage them to seek further knowledge of this truly exciting subject.

APPENDICES

APPENDIX A

THE KELLER METHOD

APPENDIX A

THE KELLER METHOD

The following description of the Keller Method of instruction is summarized from by article entitled "Good-bye Teacher. . ." by Fred S. Keller. It was published in the Journal of Applied Behavior Analysis, 1968, pages 79-89.

The Keller method of instruction, first used at the newly formed University of Brazilia in 1964 and concurrently at Arizona State University, is based on the Skinner principle of positive reinforcement, i.e., an organism tends to repeat and enjoy behavior for which it is rewarded.

In designing an astronomy course using the Keller method, there are certain features to be included:

1. The "go-at-your-own-pace" feature. The course is self-paced. It allows the student to proceed at a pace dictated only by his own ability and desires.

2. "The unit-perfection requirement for advancement." This requires that students completely master the current unit before advancing to new material.

3. "The use of lectures and demonstrations as vehicles of motivation, rather than sources of critical information." Demonstrations and laboratories are not

mandatory to completion of the course, but should be designed to stimulate interest and foster motivation.

4. The related stress upon the written word in teacher-student communication. This deviates from the lecture type courses and brings to light only those areas in which each individual has questions.

5. "The use of proctors." Student proctor/tutors, graduate assistants, or available staff are utilized to the maximum extent to provide immediate personalized exam grading, tutoring in conjunction with both examination grading and study periods, and availability during demonstrations and laboratories. The result is a much greater emphasis on the personal aspect of the education process.

Let me relate an example of how the course will operate. A student will have explained to him at the beginning of the course the criteria for completion and grading. He must complete so many units for a certain grade plus take a comprehensive final examination. He need not attend class but is encouraged to use the regular class period as a study hall in the appointed place. Here he will be able to have a proctor/tutor available for immediate help on any problems. Since he is proceeding at his own pace, he does not need to take an examination until he is ready and there is no penalty for failure, other than that of time. He is given a suggested pacing schedule and is encouraged to withdraw if the first unit is not completed in two weeks.

Having the rules in mind, the student prepares for and announces he is ready for the first examination. The person assigned to him as his personal proctor (he is one of 10-12 students assigned to this proctor) takes him to the testing-critique room for the test. It is a short test and when he is finished, he and the proctor sit down and grade it. If the student misses a few questions, he is asked to explain his answers. If he demonstrates he actually knows the material, but misinterpreted the question, he may be given credit. If he passes the exam, it is noted (immediate reward) and he is told to proceed to the next unit. If he fails, the weak areas are discussed and he will be given another chance to pass that unit. Note: there is no penalty for failure.

Throughout the term, planetarium programs and actual night observing are planned. As stated, these are not mandatory, but are timed to coincide with the pacing of most of the class. In fact they are not presented until a sizable number are ready for them.

It must be noted that one of the most essential features of the course is the personalized approach. In this regard care must be taken to insure that a proctor/tutor can give this personalized instruction, i.e., keep the group assigned to each proctor/tutor small. For classes where enrollment is high, advanced students can be used as proctors/tutors. These could be students who took the course previously and did well. It would seem necessary to safeguard objectivity somewhat here, however, by leaving the final decision on missed questions to the primary instructor for the course.

For large classes, consequently, the primary instructor's role is one of a manager and organizer. He oversees his assistants as well as organizing the learning objectives and the necessary materials for attaining those objectives.

It can readily be seen that the course given in the described manner leads to "Reward Motivated Learning." As each unit is passed, the student's success is recognized and he is not penalized for his failure.

APPENDIX B

THE COURSE

APPENDIX B

THE COURSE

<u>To the Student</u>:

This course is presented using the Keller method of instruction. It is a personalized method which utilizes the following features:

1. The course is self-paced. You proceed just as fast as your ability and desires let you. No one will require you to take any of the examinations on any particular date, or before you think you are ready.

2. You are not required to attend class. Roll will not be taken and you will not be graded down for not appearing at the scheduled class periods. However, you are encouraged to use this time and room for a study hall. A proctor/tutor will be available to answer your questions and help you in every possible way.

3. Your grade in the course will depend on the number of units you complete successfully plus your performance on the final examination. There are 18 units, corresponding to one per week for the semester. Each unit, successfully completed, gives you five points. Failure to complete a unit results in zero points. In addition, the final examination will count 20 points, making a total of 110 points. The following criteria will be used to determine

your grade: A = 95-110
B = 85-94
C = 75-84
D = 60-74
F = below 60

4. You complete a unit by passing an examination on that unit. Each examination will consist of a number of questions based exclusively on the objectives for that unit. You most answer 100 percent of these questions correctly in order to complete that unit. There is no penalty for failure, other than time, and you may take an examination as many times as it takes you to pass it. You must, however, wait at least one hour before retaking a particular examination.

5. Each of you will be assigned a proctor/tutor to grade your examinations and give you assistance when you need it. However, you may, of course, seek anyone available for help.

6. You cannot receive an incomplete for the course for any reason short of a disaster.

The objectives for each unit of the course are designed to be simply stated and self-explanatory. Each one contains one of the following key words: state, describe, explain, diagram (draw), compute, define. In addition, the entire list of objectives for each unit is prefaced by the phrase "Be able to." The meaning of each of the key words combined with "be able to" is as follows:

1. State--paraphrase or write from memory.
2. Describe--give properties or provide a written picture.
3. Explain--give the reasons for.
4. Diagram--draw a diagram or picture.
5. Compute--solve a problem.
6. Define--write a definition.

From time to time throughout the term, there will be planetarium programs and observing sessions. Again, it is not mandatory that you attend. However, you will find these to be interesting and informative. They are presented to add supplementary information to particular units. When a suitable number of students have progressed to these particular units, a time will be announced for the applicable presentation. For planetarium shows, the times will be during the regularly scheduled class time. For the observing sessions times will necessarily be at night.

This course is designed for liberal arts majors. It is conceptual in nature and not mathematically oriented, although some simple algebra is occasionally used. The textbook is appropriately written for liberal arts majors as well, and is an excellent addition to the course. The text is: Astronomy: Fundamentals and Frontiers, by Robert Jastrow and Malcolm Thompson. I believe you will find it easy to read and very interesting. All of your objectives and examination questions will be taken from the text.

However, for those who are interested, supplementary information is provided for many of the units. This will be in the form of additional references, and/or written additions. As previously mentioned, supplementary information is also provided in the form of planetarium programs and observing sessions.

HAPPY STAR GAZING AND GOOD LUCK

INTRODUCTION

The science of astronomy is undoubtedly the oldest of the true sciences. Although there are sporadic accounts of its early history, like all history, much is lost in the depths of time. There are, however, accounts of early astronomers dating back about 5000 years.

The Chinese were probably the first astronomers to record their observations. Some of these records reveal much work done prior to 3000 B.C., indicating that even at that time astronomy was not a new science. In about 2159 B.C. two Chinese royal astronomers were reportedly put to death for not predicting an eclipse. As early as 2500 B.C. the Chinese had a calendar with 365 days, adding a day every fourth year, as we do today. Inventions occurring about the year 3000 B.C. were the wheel, sailing ships, and the first furniture. Also between 2500 and 2000 B.C. iron was invented. It would be 500 to 1000 years before the first iron tools and weapons, however, their general use starting between 1000 and 500 B.C. The main civilizations of ancient times were in Egypt and the Middle East, along with China.

It was not until the sixth century B.C. that somewhat accurate accounts of inventions and discoveries were recorded. It is interesting to compare chronologically these astronomical events and the men associated with them, with the important historical events of the time. In doing so, try to picture the type of political environment along with the standard of living that existed in these particular periods of history. (Note Table A.)

Many empires came and went during the next historical period, the Middle Ages. Feudalism replaced the governmental units of the Roman Empire and provided a crude form of law and order. Lief Ericson in about the year 1000, was probably the first explorer to reach North America. In 1215 the historic Magna Carta was signed by King John of England.

Progress in astronomy was limited during the Middle Ages, with no significant advancement occurring again until the sixteenth century. As in astronomy, few significant inventions occurred during this period. Of these, gunpowder, soap, and distilled alcohol, along with the windmill, were noteworthy.

The years from 1493 to 1900 were called the Early Period of Modern Times. This was an era of scientific achievement, industrial revolution, and sweeping social change. Nearly all these changes were made in Western Europe with the Middle East and China making little progress. Consequently, these latter areas came under the influence of Western Civilization. This came about primarily as the result of scientific achievements and new world discoveries.

Table A.--Early period.

Astronomical Event or Discovery	Significant Invention	Historical Event
639-546 BC--Thales, Greek Philosopher, explains phases of the moon and measures angular diameter of sun.	1000-500 BC--General use of iron tools and weapons.	509 BC--Roman Republic founded.
569-470 BC--Pythagoras, Greek Philosopher, deduces theory of planetary motions which later is revised by Copernicus.	400 BC--Kite invented in China.	750-338 BC--Hellenic Age in Greece.
320-250 BC--Aristarchus of Greece measures distance to sun.	c350 BC--Missile engine invented in Greece.	338 BC--Greece becomes part of Macedonia. 331 BC--Alexander the Great defeats Persians and opens path to conquest of Northern India.
190-120 BC--Hipparchus of Greece founds real observational astronomy, logs stars, invents trigonometry.	200-100 BC--Lead pipes for distributing water first used in Rome. 100-1 BC--Concrete (Italy)	146 BC--Romans conquer Greece. 55-54 BC--Julius Caesar led Roman invasion of Britain. c7 BC--Birth of Christ.
139-161 AD--Ptolemy of Greece formulates theory of celestial motions using epicycles, deferants, eccentrics, and equants.	1-200 AD--Glassblowing (Egypt) Carpenter's plane (Italy) Paper (China)	70 AD--Romans, under Titus, captured and destroyed Jerusalem.

The new world, bringing with it many of the advanced ideas from Western Europe, was able to rid itself of European influence. The underdeveloped areas of Africa, Asia, and the Middle East, however, remained under European control until well into the 1900's.

The basic Renaissance idea of individual freedom became a cultural force during this period. Important cultural achievements resulted, including masterpieces of art, literature, and architecture. Discoveries such as those of Copernicus, Galileo, and Newton revolutionized science. The developing philosophies of the day stressed humanism and the importance of man and his enjoyment of life.

Progress in astronomy leaped forward during this period. With little happening during the Middle Ages man was beginning to find his insignificant place in the universe. Again let us compare some astronomical discoveries with inventions and important historical dates of this period. (Note Table B.)

As can be seen by the previous list, progress in astronomy and in inventions made giant strides forward during the early modern times. This was particularly evident in the nineteenth century with the industrial revolution. Most of the great historical events were overshadowed by scientific and industrial advancement.

As the twentieth century began, this phenomenal progress would continue. Interrupted somewhat by the wars and the depression, advancement would be made at an amazing

Table B.--Early period of modern times.

Astronomical Event or Discovery	Significant Invention	Historical Event
1543--Copernicus publishes heliocentric theory.	1300-1400--Firearms appear in Europe. Mechanical lock (Italy).	1492--Columbus sails to the New World.
1546-1601--Tycho Brahe makes diligent and accurate observations which will be used later by Kepler and others.	1400-1500--3 masted ship built in N. Europe.	1519-1522--Magellan commands first voyage around world.
	1500-1600--Coal is being used instead of wood in England for firing bricks, brewing and other manufactures.	1532--Pizarro begins Spanish conquest of Incas.
		1588--Royal Navy defeats Spanish Armada and establishes itself as great naval power.
1609--Galileo improves telescope and in 1610 discovers sunspots, satellites of Jupiter, phases of Venus, and surface irregularities of the moon.	1600-1650--Submarine invented by Drebbel in Holland. Pascal invents adding machine.	1607--Jamestown colony founded.
1616--Kepler completes his three laws of planetary motion.		1613--Romanov becomes Czar of Russia and begins 300 year Czarist rule.
		1620--Plymouth colony founded.
1666--Newton makes first reflecting telescope; establishes that sunlight is a blend of colors that a prism will disperse; this lays foundation for spectroscope.	1650-1700--Galileo invents pendulum clock. Moreland invents megaphone in England. Bottle cork for champagne invented by Frenchman Perignon. Plate glass also invented in France.	1688--James II deposed in England in the Glorious Revolution.
1676--Royal observatory at Greenwich founded. Roemer discovers it takes time for light to travel.		

Table B.--Continued.

Astronomical Event or Discovery	Significant Invention	Historical Event
1687--Newton publishes law of gravity. 1705--Halley predicts return of comet. 1718--Halley detects motions of Sirius and Arcturus. 1757--Achromatic telescope invented by Dolland. 1781--Hershel discovers Uranus. 1783--Hershel deduces motion of sun through space. 1790--Guinand successfully makes large disks of flint glass (used in telescopes).	1709--Iron smelting with coke (England) 1738--Spinning machine (England) 1750--Cast steel (England) 1769--James Watt invents improved steam engine (England). 1774--Cylinder boring maching (England) 1785--Chlorine bleach (France) 1793--Cotton gin (America) 1798--Optical glass (Swiss)	1763--Treaty of Paris ends Seven-Years War in Europe and French and Indian War in America. 1776--Declaration of Independence. 1789--French Revolution begins.
1800's:		
1801--Piazzi discovers first asteroid. 1803-1804--Hershel discovers revolution of binary stars. 1815--Fraunhofer first measures lines in solar spectrum. 1833--Vast meteor shower in America.	1800--Electric battery (Italy) 1805--Railroad locomotive (England) 1807--Steamboat (America) 1820--Calculating machine (England) 1827--Water turbine (France)	1815--Napoleon defeated at Waterloo. 1824--Spanish rule in Latin America ended by Bolivar and Sucre. 1847--Liberia established as first independent Negro republic in Africa. 1853-1854--Commodore Perry opens Japan to trade.

Table B.--Continued.

Astronomical Event or Discovery	Significant Invention	Historical Event
1840--Canals on Mars proposed by Beer and Malder 1842--Doppler evolves method of measuring line-of-sight velocities of light. 1846--Neptune discovered by Galle. 1851--Foucault pendulum proves rotation of earth. 1862--Velocity of light found experimentally. 1868--Helium discovered on sun. 1878--Red spot on Jupiter discovered. 1895--X-rays discovered by Roentgen. 1897--Yerkes observatory opened.	1831--Reaping machine (Amer) 1835--Revolver (Amer) 1836--Telegraph (Eng; Amer) 1839-1840--Photography (France, Eng) 1841--Vulcanized rubber (Amer) 1846--Sewing machine (Amer) 1852--Gyroscope (Amer) 1859--Gasoline engine (Fr) 1866--Dynamite (Sweden) 1867--Typewriter (Amer) 1876--Telephone (Amer) 1877--Phonograph (Amer) 1880--Filament lamp (Amer) 1884--Rayon (France) 1887--Electric motor (Amer) 1884-1890--Automobile (Ger) 1896--Radio (Italy) 1897--Diesel engine (Ger)	1865--American Civil War ended. 1867--Canada established as free country. 1869--Suez Canal opened. 1882--Great Britain invades and occupies Egypt. 1898--U.S. takes control of Guam, Puerto Rico, and Philippines following Spanish-American War.

pace. Einstein's theory of relativity and the development of mass production are probably the two most influential factors of this period. As the industrial revolution was to the nineteenth century, so the technological revolution is to today. To compare inventions, astronomical discoveries, and historical events in a list would surely be too great a task for this introduction. Suffice it to say that more progress has been made in all areas (including social and humanistic areas) in this century, than in all the previous history of mankind.

Note: Information in the text on significant dates in astronomy along with column one of the tables was taken from Field Book of the Skies, by William T. Olcott, pp. 404-411. The column on inventions was taken from the Encyclopedia Americana, International Edition, 1973, Volume 15, pp. 330-333. The "Historical Event" column was taken from the World Book Encyclopedia, 1972 edition, Volume 21, pp. 352-362.

Unit I--Introduction

Assignment: Study pp. I-1 to I-23

Objectives:

Be able to:

1. State the theory of Copernicus and why he was attempting to describe what he saw.
2. State a method for proving that the earth rotates and revolves. The proofs listed in the text are suitable, but not mandatory.
3. Diagram and explain the eight phases of the moon.
4. Diagram the solar and lunar eclipses showing the relative positions of the sun, earth, and moon during each.
5. Describe how the moon and the sun affect tides. Be sure to include which phases of the moon cause highest and lowest tides.
6. Explain the difference between sidereal time and solar time.
7. Describe the celestial sphere and the motions of the sun and planets on the celestial sphere.
8. Define each of the terms below:

1. Planet	8. Eclipse (solar and lunar)
2. Parallax	9. Waxing celestial body
3. Rotation	10. Waning celestial body
4. Revolution	11. Tide (ocean and land)
5. Precession	12. Neap tides
6. Nutation	13. Spring tides
7. Phase	14. Celestial sphere

15. Declination
16. Greenwich meridian
17. Vernal equinox
18. Right ascension
19. Solar day
20. Sidereal day

Supplementary Information:

During the first day of class there will be a 20-minute planetarium presentation on relative distances in the universe. I think you will find it interesting. At the end of the program, the current sky will be presented. In Unit II you will be required to learn a number of stars and constellations. Consequently, this may serve as a head start.

Additional Reading for Interested Students:

Goldreich, Peter. "Tides and the Earth-Moon System," Scientific American, CCXXVI (April, 1972), 42-52. (Friction causes days to get longer and moon to recede from the earth.)

Hardie, R. W., and M. E. Krebs. "Finding Sidereal Time," Sky and Telescope, XLI (May, 1971), 288-289. (Explains several ways of determining and using sidereal time.)

To the Instructor: The following is the narrative for the planetarium program. Slides of the various ideas such as comparison of sizes of the earth and sun will be inserted when appropriate. The background should include the planetarium sky throughout the program. Note: "Cosmic Zoom" is available for renting from the Instructional

Media Center, Michigan State University, East Lansing, Michigan.

Planetarium Narrative:

Quasars! Quasi-stellar objects! Galaxies! Magellanic Clouds! Pulsars! These are some of the enormous and fast-moving objects you will become familiar with in this course. Their dimensions, their position in space, their velocities, at this point in your astronomy education are probably just figures--unrelated numbers that don't mean much of anything. What follows will give you some perspective as to the sizes of things in the universe.

Let's start with a unit of measurement with which we are all familiar--the inch. The inch is fairly small when compared with some things. A fisherman who has caught a 10-inch trout, thinks a one-inch minnow is pretty small. Furthermore, there are 63,360 inches in a mile and it is 2,851,200 inches from the Air Force Academy to Denver. As you can see, an inch is indeed small. Or is it? What about a football team that has fourth down on the one-inch line? Or what about a horse player whose horse lost by one inch at the race track? The point is that distance is really relative to that which it is compared.

If we begin with the smallest of known objects and go through to the largest known distances, maybe we can get a feel for relative distances. A proton has a diameter of about 1/100,000 of an Angstrom. (An Angstrom is about 1/40 millionth of an inch.) A Hydrogen atom containing one proton and one electron is about one Angstrom across. If we consider next the size of a human being, we find that he is 18 billion Angstroms tall--about six feet. Our numbers are already into the billions and we have reached only to the top of a man's head.

Since this is an astronomy course, let's look at some "astronomical" (no pun intended) distances. The diameter of the earth is about 8000 miles. Let's say for simplicity, it is 10,000 miles. A man's height is about 1/1000 of a mile. So a simple calculation determines that the earth's diameter is some 10 million times larger than the height of a man. The sun's diameter is 100 times larger than a man. And the distance from the earth to the sun is about 100 times larger than that, or 100 billion times larger than a man.

Next, consider a unit of measurement that is used by astronomers--the light year. This is simply the distance that light will travel in one year, barring any interruptions. It is about six trillion miles. To illustrate this distance, consider the following: It takes light about 1-1/3 seconds to get from the moon to the earth; it takes about eight minutes to travel from the sun to the earth; and some five hours from the sun to Pluto, at the outer edge of our solar system.

Now the nearest star to our solar system is called Alpha Centauri. It takes light 4-1/4 <u>years</u> to travel to us from this star. Furthermore, the average distance between stars in our galaxy is about 10 light years. Moreover, the diameter of the Milky Way is about 100,000 light years. If you are beginning to feel a little insignificant at this point, wait just a minute.

With very few faint exceptions, everything you see in the sky is part of the Milky Way. Beyond our galaxy lie many other galaxies. The closest ones, the Magellanic Clouds, which are irregular galaxies observable from the southern hemisphere, are 160,000 light years from our galaxy. The great spiral galaxy, Andromeda, is some two million light years away. Finally, the most distant observable objects, Quasars, approach 10 billion light years away. Beyond that, who knows?

Let us further illustrate these distances with the film "Cosmic Zoom."

Now you may feel insignificant!

Unit II--The Changing Night Sky and Contents of the Universe

Assignment: Study pp. I-23 to I-35 and pp. 3 to 20; answer the questions on p. 20.

Objectives:

Be able to:

1. Explain why we see different stars in the sky at different times of the year. (A diagram will serve quite well.)
2. Identify six of the prominent constellations visible in the current night sky along with one prominent feature in each. (A list of constellations and features will be made available to you.)
3. Explain why the North Star appears to be almost stationary as time passes, while the other heavenly bodies appear to move.
4. Draw a simple diagram of the Galaxy and locate the position of the sun (viewed both edge-on and face-on).
5. Describe the three forces that hold the universe together and their relative strengths.
6. Define each of the terms below:

1. Zenith	8. Galaxy
2. Optical Double Star	9. Light year
3. Polaris (North Star)	10. Magellanic Clouds
4. Binary Stars	11. Nuclear force
5. Circumpolar Stars	12. Electromagnetic force
6. Solar system	13. Gravity
7. Multiple stars	

Supplementary Information:

One of your objectives for this unit is to be able to identify constellations in the current night sky. You will find a current sky map with your study guide which will point out which constellations and prominent features you should know. Also available during your regularly scheduled class periods is the planetarium sky. Your examination on this objective will be held in the planetarium, or if you choose, outside at a pre-arranged meeting time. I urge you to study the real sky throughout the semester whenever possible. You will discover things that are truly beautiful and interesting.

It is common knowledge that the stars are used for navigation purposes both by ships at sea and by aircraft and spacecraft. But it is not common knowledge that birds may use the stars to start migration and to navigate with while on their journey. Stephen T. Emlen has written an article in this respect called, "The Celestial Guidance System of a Migrating Bird." It was published in the July, 1969, issue of Sky and Telescope.

In addition, William S. Kals' article in the June, 1967, Sky and Telescope called "Polynesian Navigation," attempts to show how early peoples navigated throughout the Pacific Ocean. His conclusions point to celestial navigation.

To the Instructor: The following constellations along with the prominent feature(s) of each are provided. They are listed as to the particular season of the year in which they are visible in the early evening sky. (40 degrees north latitude is assumed.)

SPRING

Gemini (Castor, Pollux)

Auriga (Capella)

Cancer (Praesepe)

Leo (Regulus, Denebola)

Canis Minor (Procyon)

Corvus (Geniah)

AUTUMN

Square of Pegasus (Alpheratz, M-31)

Pisces (Cirlet)

Aries (Hamel)

Cetus (Menkar)

CIRCUMPOLAR

Ursa Major (Pointers, Mizar)

Ursa Minor (Kochab, Polaris)

Cassiopeia (Shedar)

SUMMER

Lyra (Vega)

Cygnus (Deneb)

Aquila (Altair)

Sagitarius (Nunki)

Scorpius (Antares, Shaula)

Corona Borealis (Alphecca)

Bootes (Arcturus)

Virgo (Spica)

WINTER

Taurus (Aldebaran, Pleiades, Hyades)

Orion (Betelgeuse, Rigel, M-42)

Canis Major (Sirius)

Unit III--The Nature of Light

Assignment: Study pp. 23-35; answer the questions on pp. 35-36.

Objectives:

Be able to:

1. Explain why light can traverse space, while sound cannot.
2. Explain the differences among the elements of the electromagnetic spectrum and explain why we can see only a portion (light) of that spectrum.
3. Compute the relationship between wavelength and frequency.
4. Explain what determines the wavelength at which the intensity of radiation is the strongest.
5. Explain the apparent shift in wavelengths of moving objects (Doppler shift).
6. Compute the relative speed of a celestial object from the Doppler shift.
7. Define the following terms:

1. Light	10. Microwaves
2. Electric field	11. Wavelength
3. Electric wave	12. Gamma ray
4. Electromagnetic radiation	13. Angstrom
5. Electromagnetic spectrum	14. Wein's law
6. Magnetic wave	15. Doppler shift
7. Visible spectrum	16. Red shift
8. Ultraviolet light	17. Blue shift
9. Infrared light	18. Frequency

Supplementary Information:

The Doppler shift is a phenomenon that has enabled astronomers to discover many things about the universe. For example, the visual shape of the Milky Way, the speed of stars in our local area relative to the solar system, and, via the velocity of Quasars, some notion of the cosmology of the universe. During this unit a 15-minute film will be shown in the planetarium. Its title is "Sound Waves and Stars: The Doppler Effect." Included in the film are definitions of terminology and visualizations of sound and light waves. In addition, it explains the source of the Doppler effect as it relates to stars and the nature of the universe.

Further interesting reading pertaining to the nature of light is an article by Robert S. McMillan and John D. Kirszenberg published in the November, 1972, issue of Sky and Telescope. It is entitled "A Modern Version of the Ole Roemer Experiment," and begins on page 300. It tells of the planet-satellite method Roemer used to determine the speed of light and a modern adaptation of the experiment.

To the Instructor: The film "Sound Waves and Stars: The Doppler Effect," is available for renting from the Bureau of Audio Visual Instruction, University of Wisconsin, Madison, Wisconsin.

Unit IV--The Tools of the Astronomer

Assignment: Study pp. 39-62, 70-75 (pp. 62-70 optional); answer the questions on p. 75.

Objectives:

Be able to:

1. Draw a simple telescope (both reflecting and refracting), label the parts, and trace light rays through to an observer's eye.
2. Explain why a telescope with a larger objective lens will have less diffraction effect than one with a smaller objective lens.
3. Describe another limitation on space observations (other than diffraction), namely atmospheric blurring or bad seeing.
4. Name and describe two types of reflecting telescopes and one advantage of each.
5. State two advantages of a radio telescope over an optical telescope.
6. State two important differences between radio and optical telescopes.
7. Explain the principle of the spectroscope.
8. Describe two types of spectroscopes and the light principle that applies to each.
9. Define the following terms:

1. Telescope	4. Lens
2. Refraction	5. Ocular (eye piece)
3. Prism	6. Focus

7. Diffraction
8. Atmospheric blurring
9. Diffraction disk
10. Good and bad "seeing"
11. Reflecting telescope
12. Newtonian reflector
13. Cassegrain reflector
14. Radio telescope
15. Spectroscope
16. Spectrograph
17. Spectral lines
18. Prism spectroscope
19. Grating spectroscope

Supplementary Information:

To get an idea of some of the things astronomers do in observing the sky, one should actually do some observing using a telescope. Thus during the time you are working on this unit, there will be outdoor observing sessions. We will be using both the refracting and reflecting types of telescopes with various types of magnification and mountings. Pre-arranged meeting times will be posted.

A familiarity with the appearance of the following types of objects would be desirable prior to the session, as we will be looking at these as well as more common objects.

1. Open star cluster (Plate 9)
2. Globular cluster (Plate 10)
3. Spiral galaxy (Plate 12)
4. Nebula (Plate 4)
5. Double star (simply a double point of light)

Additional Reading for Interested Students:

Almost every issue of Sky and Telescope includes an article on some observatory. These include radio and optical telescopes located throughout the world.

To the Instructor: The following objects can be observed at various times of the year, depending on the availability of suitable telescopes and binoculars. It is summarized from a pamphlet by James Mullaney and Wallace McCall called The Finest Deep Sky Objects. Listed in order of increasing right ascention, all objects are visible from 40 degrees north latitude.

	NAME	CON.	R.A.	DEC.	MAG.	TYPE OF OBJECT
1.	M-31	And	00-40	+41.0	5	Spiral galaxy
2.	Eta	Cas	00-46	+57.6	4+8	Double star
3.	Gamma	Ari	01-51	+19.1	5+5	Double star
4.	Gamma	And	02-01	+42.1	2+5+6	Triple star
5.	NGC 869	Per	02-16	+56.9	4	Open cluster
6.	NGC 1535	Eri	04-12	-12.9	9	Planetary nebula
7.	Eta	Ori	05-22	-02.4	4+5	Double star
8.	M-42	Ori	05-33	-05.4		Diffuse nebula
9.	M-35	Gem	06-06	+24.3	5	Open cluster
10.	Beta	Mon	06-26	-07.0	5+5+6	Triple star
11.	Alpha	CMa	06-43	-16.6	-1+9	Double star
12.	Alpha	Gem	07-31	+32.0	2+3+10	Triple star
13.	M-44	Cnc	08-37	+20.2	3.5	Open cluster
14.	M-67	Cnc	08-48	+12.0	6	Open cluster

	NAME	CON.	R.A.	DEC.	MAG.	TYPE OF OBJECT
15.	M-81	UMa	09-52	+69.3	8	Spiral galaxy
16.	M-82	UMa	09-52	+69.9	9	Irregular galaxy
17.	Gamma	Leo	10-17	+20.1	3+4	Double star
18.	Gamma	Vir	12-39	-01.2	4+4	Double star
19.	Alpha	CVn	12-54	+38.6	3+5	Double star
20.	Zeta	UMa	13-22	+55.2	2+4	Double star (Mizar)
21.	M-3	CVn	13-40	+28.6	6	Globular cluster
22.	Epsilon	Boo	14-43	+27.3	3+5	Double star
23.	M-5	Ser	15-16	+02.3	6	Globular cluster
24.	Nu	Sco	16-09	-19.3	4+6+7+8	Quadruple star
25.	M-4	Sco	16-21	-26.4	6	Globular cluster
26.	Alpha	Sco	16-26	-26.3	1+6	Double star
27.	M-13	Her	16-40	+36.6	6	Globular cluster
28.	Alpha	Her	17-12	+14.4	3+5	Double star
29.	M-92	Her	17-16	+43.2	6	Globular cluster
30.	M-7	Sco	17-51	-34.6	3	Open cluster
31.	M-8	Sgr	18-01	-24.4		Lagoon nebula
32.	M-22	Sgr	18-33	-24.0	6	Globular cluster
33.	Epsilon	Lyr	18-43	+39.6	5+5+5+6	Quadruple star
34.	Beta	Cyg	19-29	+27.9	3+5	Double star
35.	M-27	Vul	19-57	+22.6	8	Planetary nebula
36.	M-2	Aqr	21-31	-01.0	6	Globular cluster
37.	Mu	Cep	21-42	+58.6	4	Red star
38.	Delta	Cep	22-27	+58.2	4+8	Double star

Unit V--The Message of Starlight

<u>Assignment</u>: Study pp. 79-104; answer the questions on pp. 104-105.

<u>Objectives</u>:

Be able to:

1. State what fact enables us to determine the composition of stars.
2. Describe the structure of a simple atom and how an atom can reach an excited state.
3. Explain how an atom of hydrogen can emit a flash of light.
4. Explain the difference between emission lines and absorption lines and how they are used in identifying the composition of stars.
5. Explain how the temperature of a star affects the strength of absorption lines of hydrogen.
6. State the seven classifications of stellar spectra and their approximate temperature ranges (°K).
7. Explain how the spectra of molecules differ from spectra of atoms.
8. Define the following terms:

   1. Atom
   2. Electron
   3. Angstrom
   4. Ground state
   5. Ion
   6. Excited state
   7. Photon
   8. Lyman lines
   9. Balmer lines
   10. Emission Spectra
   11. Bright line Spectra
   12. Absorption Spectra

13. Dark lines
14. Astrophysics
15. Ionized helium
16. Neutral helium
17. Spectral type

Supplementary Information:

Astronomers generally use the Kelvin scale to measure temperatures. The reason for this is that the Kelvin, or Absolute, scale begins at absolute zero. (Absolute zero is believed to be the coldest possible temperature--that is, the temperature at which all molecular motion ceases.) Absolute zero equals zero degrees Kelvin.

There are two other temperature scales in common use: the Fahrenheit scale and the Centigrade (or Celsius) scale. Kelvin is related closely to the Centigrade scale in that one degree difference is the same on both scales. Absolute zero on the Centigrade scale is -273 degrees. Thus, zero, the freezing point of water on the Centigrade scale, is +273 degrees of the Kelvin scale. Moreover, the boiling point of water being +100 degrees Centigrade, is +373 degrees Kelvin. The following simple formula can be used to convert Kelvin to Centigrade and vice versa:

$$C = K + 273.$$

In order to convert Kelvin to Fahrenheit degrees, it is convenient to convert first to Centigrade and then from Centigrade to Fahrenheit. The following formula can be used to convert Centigrade to Fahrenheit:

$$C = 5/9\ (F-32),\ \text{or}\ F = 9/5\ C + 32.$$

Thus the freezing point of water being zero Centigrade is seen to be +32 degrees Fahrenheit and the boiling point being +100 degrees Centigrade is +212 degrees Fahrenheit. Absolute zero on the Farhenheit scale is -459 degrees.

Now consider the surface temperature of the sun, approximately +6000 degrees Kelvin. The corresponding Centigrade temperature is +6273 degrees. The Fahrenheit temperature is:

$$\begin{aligned} F &= 9/5\ (6273) + 32 \\ &= 11323. \end{aligned}$$

This should give you a feel for the enormous temperatures found in stars. Also note that +6000 degrees Kelvin is just the surface temperature. Interior temperatures, as you shall see, range much higher.

<u>Additional Reading for Interested Students</u>:

Connes, Pierre. "How Light Is Analyzed," *Scientific American*, CCXIX (September, 1968), 72-82. (Shows methods used in spectroscopic analysis.)

Unit VI--The Hertzsprung-Russell Diagram

<u>Assignment</u>: Study pp. 107-128; answer the questions on pp. 128-129.

<u>Objectives</u>:

Be able to:

1. Explain the relationship between temperature and color in stars.
2. Explain the differences in brightness among stars with different apparent magnitudes.
3. Describe the main sequence in terms of temperature-luminosity relationships.
4. Describe the main sequence in terms of the mass of the stars on it (including limits).
5. Describe the significance of red giants and white dwarfs in terms of relative ages of stars.
6. Describe cepheid variables in terms of temperature and luminosity and locate them on an H-R diagram.
7. Explain the importance of cepheid variables with respect to distance determination.
8. Describe three differences between Novas and cepheid variables.
9. Define the following terms:

1. Spectral type	6. Luminosity
2. Intrinsic brightness	7. Absolute luminosity
3. Ultraviolet radiation	8. Apparent luminosity
4. Infrared radiation	9. Absolute magnitude
5. Brightness	10. Apparent magnitude

11. Erg
12. Main sequence
13. H-R diagram
14. Dwarf
15. Supergiant (red and blue)
16. Giant (red and blue)
17. White dwarf
18. Red dwarf
19. Variable stars
20. Cepheid variable
21. Irregular variables
22. Pulsation
23. Nova

Supplementary Information:

The Hertzsprung-Russell diagram was a very significant development in astronomy. It links together properties of stars that enable astronomers to learn more about evolution, stellar distances, temperatures, internal structure, size, and brightness. A two-part article in the May and June, 1966, issues of Sky and Telescope entitled "The Hertzsprung-Russell Diagram Today" gives a short history of the concept and discusses some new developments. It was written by a frequent contributor to Sky and Telescope, Ms. Margherita Hack. I suggest you read it to further your understanding of this unit.

In addition, if available, a 29-minute film entitled "The Nature of the Stars" will be shown in the planetarium during this unit. It was produced by National Educational Television and presents classifications of stars, their physical properties, magnitude, size, and possible evolution. The H-R diagram is discussed along with an explanation of population I and II stars.

To the Instructor: "The Nature of the Stars" is available for renting from the Audio-Visual Center of Indiana University.

Unit VII--Nuclear Energy Sources

<u>Assignment</u>: Study pp. 131-143; answer the questions on p. 143.

<u>Objectives</u>:

Be able to:

1. Describe a nuclear fission process and state the reason why it is not the prime source of energy in stars.
2. State the particles involved in nuclear fusion inside stars and the resulting by-products.
3. Describe how two nuclei of carbon^{12} can collide to form Sodium^{23}+p or Ne^{20} and He^{4}.
4. Explain simply by using hydrogen fusion how energy is produced in nuclear fusion. Include the formula for conversion of mass to energy--$E = MC^2$.
5. State the most important factor leading to sufficient temperature to support nuclear fusion in stars.
6. Explain briefly the origin of the heavy elements.
7. Explain why nuclear fusion power cannot be harnessed on the earth.
8. Define the following terms:
    1. Nuclear fission
    2. Nuclear fusion
    3. Proton (p)
    4. Neutron (e)
    5. Electron (e^-)
    6. Positron (e^+)
    7. Neutrino (ν)
    8. Gamma ray (γ)
    9. Deuteron (d)
    10. Isotope

<u>Supplementary Information</u>:

"It has been conclusively demonstrated by hundreds of experiments that the beating of drums will restore the sun after an eclipse." Gregory

Albert Einstein is probably the greatest scientist/mathematician who ever lived. His discoveries and theories have opened the door to a completely new way of life in the twentieth century. Nuclear energy and its by-products are a direct result of Einstein's work. Examples include nuclear power plants, defense systems, discovery of the probable energy mechanism of stars, and explanations of the universe.

The question arises: How did Einstein come to make his discoveries? What methods did he use to arrive at his conclusions? In general, how do scientists go about their work? The answers are not simple. Some discoveries are made by sheer luck, being in the right place at the right time. A scientist may be working on one thing and all of a sudden hit upon some startling development. One example of this was the discovery of the planet Uranus in 1781. The German-English astronomer William Hershel was making a routine telescopic survey of the sky in the constellation of Gemini. He noticed that there was an object that was not a point of light, but presented a small disk appearance. Believing it to be a comet, he followed its motion for some time and eventually calculated its orbit. Finding it to be circular and lying outside the orbit of Saturn, he deduced that it must be a planet.

Stumbling onto discoveries such as Uranus is indeed rare, however. Nearly all progress in science, as well as other fields, is the result of considerable study and hard work. The method used in these endeavors is known as the "scientific method."

The method itself is a straightforward, mechanical tool when observed in an elementary fashion. It consists first of the observation of some unexplained phenomenon. Next a hypothesis as to the cause or explanation of the phenomenon is advanced. This hypothesis is then tested to see if it is valid for this phenomenon and in general for like phenomena. If it does not work, then revisions must be made or a new hypothesis must be formulated and tested.

As you can see, this method is simple, straightforward, foolproof, and unexciting. If carried through to a conclusion it will never fail. Right? Wrong! It is surely not that simple. It is not a magic formula that will lead easily to the solution of any problem. The scientific method is exciting. In reality there are accidents, such as the above-mentioned discovery of Uranus. There are hunches that lead to startling discoveries--the discovery of Pluto for example. Even today there are some scientists who feel that there is a tenth or even eleventh planet. Sometimes wrong data are gathered, leading to false or inconsistent conclusions. Indeed, science does not proceed in the organized, unfaltering way as it is sometimes portrayed.

The scientific method is not confined to scientists. Nearly all disciplines use it. Authors feel a need to write. Their books are their hypotheses and the public, their tests. Sometimes wrong conclusions are the results of these tests. A man may be an excellent writer, but no one buys his book. He concludes that he cannot write. Maybe a politician uses a poll to test his hypothesis on a certain issue. The results either support or deny his hypothesis. He tries again, altering or expanding upon the original theme. Although he may not realize it, he is utilizing the methods of science.

The point of all this is that scientists and astronomers in particular, proceed to their goals just as those in any other discipline. They are human. They are fallible. Einstein, it is rumored, could not do his own income tax. But just as psychologists, political scientists, historians, administrators, and businessmen are dedicated to their ends, scientists, too, are dedicated in seeking their goals. The ultimate goal of everyone, after all, is a broad and complete understanding.

<u>Note</u>: Answering the questions, "Is a scientific discovery ahead of its time?" and "Are scientific creations any less unique than artistic creations?" is the subject of the <u>Scientific American</u> article, "Prematurity and Uniqueness in Scientific Discovery." It was published in the December, 1972, issue and was written by Gunther S. Stent.

Unit VIII--Stellar Evolution

Assignment: Study pp. 145-176; answer the questions on pp. 176-177.

Objectives:

Be able to:

1. Describe the birth of a star from a gas cloud through the protostar and the factors that lead to formation.
2. State the time it takes for a star of one solar mass to arrive at the main sequence after it begins collapse and the percentage of its liftime it will spend as a main sequence star (as predicted by high speed computers).
3. Explain why a more massive star will spend less time on the main sequence than a less massive star.
4. Describe what causes a star to heat up to a temperature that will support nuclear reactions.
5. Draw roughly a star's path on the H-R diagram from a gas cloud through a white dwarf.
6. Describe two possible stages a one solar mass star goes through in its final period of evolution.
7. Describe a supernova and distinguish between it and a planetary nebula. Include the relative masses of the stars from which they originate and the relative velocities of the escaping material.
8. State the diameter and masses of neutron stars and black holes.

9. Define the following terms:

1. Protostar
2. Core of a star
3. Gravitational contraction
4. Envelope
5. Constant luminosity phase
6. Helium flash (plus note "2" at bottom p. 161)
7. Planetary nebula
8. Supernova
9. Pulsar
10. Neutron star
11. Black hole
12. LGM

Supplementary Information:

During this unit a program called "The Death of Stars" will be presented in the planetarium. It examines the three possible final stages of stellar evolution.

To the Instructor: The following planetarium narrative is adapted from a Scientific American article by Roger Penrose called "Black Holes." It appeared in the May, 1972, issue on pages 38-46. The story about gravitational collapse and the ants is from "Gravitational Collapse," printed in the November, 1967, issue of the same magazine. It is by Kip S. Thorne.

Throughout our lifetime and many lifetimes to come, the appearance of the stars in the heavens will not change. They will keep essentially their same relative positions among the many thousands of stars and will exhibit almost no hint of altering this staid condition. But as you will learn in your study of stellar evolution, stars are born, evolve through the main sequence, and die. The rate at which stars exhaust their fuel supply and hence the length of their stellar life, is dependent on the mass of the hydrogen gas of which the body was originally composed.

Our sun, being a relatively average star, will follow a typical evolutionary path. In about five billion years it will have consumed so much of its hydrogen in thermonuclear reactions that it will evolve to a star of the type known as a red giant. Evolutionary theory predicts that the sun will grow to some 250 times its present diameter of 850,000 miles, devouring Mercury, Venus, and probably the earth in the process.

As it consumes more and more of the available nuclear fuel (helium and heavier elements as well as hydrogen), the oversized sun will reverse its expansion and contract down through its present diameter to roughly the size of the earth. It will then have evolved into a white dwarf and its contraction will halt. The electrons of its atoms will have become packed together so tightly that one of the laws of quantum mechanics will come into play and give rise to an effective pressure strong enough to prevent further contraction. The law is the Pauli exclusion principle, which states that no two electrons can occupy the same energy state. By this time the sun's density will be enormous; a golf ball filled with its substance would have the mass of a couple of large houses. A person lying on its surface would be squashed so flat that he would have no more thickness than the wax on your kitchen floor. All that remains for it is to cool off to its final dead state as a black dwarf.

Nothing on the earth has a density anywhere near the density of a white dwarf. Nevertheless, many white dwarfs and red giants are observed in the heavens. They are part of the evolutionary history of perfectly normal stars such as the sun. Betelgeuse in the constellation of Orion the Hunter and Anteres in Scorpius are naked eye stars that are red giants. White dwarfs, of course, are not bright enough to be seen without optical aid. Moreover, the theory of stellar evolution to white dwarfs fits these observations closely. Not all stars, however, can follow this "normal" evolutionary path. In the early 1930's it was found that there was a maximum mass above which a white dwarf cannot sustain itself against further gravitational contraction. The gravitational pull toward the star's center would be even greater than the counteracting pressure from the action of the Pauli exclusion principle on the electrons. This maximum mass limit is not much greater than the mass of the sun. Recent calculations give a value lower than 1.4 solar masses. Many observed stars have a mass greater than 1.5 solar masses. What can be their ultimate fate?

Consider a star that has twice the mass of the sun. Like the sun, it will expand to enormous size after consuming much of its original hydrogen fuel. Then it will contract again. It has no stable equilibrium state that will enable it to settle down as a white dwarf. Therefore the star, or a substantial portion of it, will collapse through the white dwarf size. There are extreme temperatures and densities that are involved, and it will undergo processes that lead it to explode catastrophically. Such exploding stars, called supernovas, have been observed in our galaxy and in other galaxies. A supernova will outshine even an entire galaxy for a few days. Perhaps as much as 90 percent of the star's mass could be ejected. Only a collapsed core of the star would remain at the center of a rapidly expanding cloud of gas. (The Crab Nebula is such a cloud.) The core is much too small and compressed to form a white dwarf; it can find equilibrium only as a neutron star.

Even by comparison with a white dwarf a neutron star is tiny. The contraction from a white dwarf to a neutron star is comparatively even more than the reduction from the sun to a white dwarf. It is even more than the contraction from a red giant to the sun. A neutron star may be only 10 kilometers in radius, or only about one-seven-hundredth the radius of a white dwarf. The density of a neutron star could be more than 100 million times the extraordinary density of a white dwarf. A golf ball filled with material from a neutron star would have the mass of a large asteroid such as Juno, a minor planet 118 miles across. That wax on your kitchen floor that represented your squashed body is now too thin to retard black heel marks. Indeed, a neutron star can be regarded as an oversized atomic nucleus, the only essential difference being that it is held together by gravitational rather than nuclear forces. Most of its electrons have been pushed into protons, with the result that the protons have become neutrons. It is now the Pauli exclusion principle acting on the neutrons that supplies the effective force preventing further collapse.

It was in 1967 that the first neutron star was discovered. Looking with a radio telescope into the Crab Nebula (a supernova remnant) the regular beat of a pulsar was observed which later was deduced to be a rotating neutron star.

As in the case of white dwarfs, there is a maximum possible mass above which a neutron star would not be able to sustain itself against still further gravitational contraction. The exact value of this mass is uncertain but it ranges from 0.7 solar masses to about three solar masses depending on whether the heavier subatomic particles called hyperons are present in addition to protons and neutrons. Since there are stars whose mass is more than 50 times the mass of the sun, a further evolutionary object should be possible. Also it is unlikely that such stars of 50 or more solar masses would throw off enough mass to always be below the neutron star limit. What other forms of condensed matter could exist, with the densities even in excess of the fantastic value that is maintained inside a neutron star?

The answer is the black hole. A black hole is a region in space which a star (or a collection of stars or other bodies) has fallen and from which no light, matter, or signal of any kind can escape. Consider a star of one solar mass. A neutron star of this mass would have to contract to only one-third of its diameter to become a black hole. The size of this sphere for an object with the mass of our sun would be about four miles in diameter. Larger black holes are possible, but they would be the result of the collapse of a star, or collection of stars, whose total mass was greater than that of the sun.

Let us call the surface of the hole the critical event horizon. Inside this surface nothing can escape. Outside of this surface signals emitted can escape. The reason why no light could escape is explained in Einstein's general theory of relativity. Intuitively it is because light has mass and is subject to the gravitational field of the black hole.

If one considers the effect of a black hole on light in a space-time representation, it would appear somewhat differently than in a normal three-dimensional picture. As an example, light emitted from a spherical light bulb on the earth, at progressively later times would give a series of gradually large spheres. But because of the enormous gravitational force of a black hole, emitted light would curve. If we suppress one of the spacial dimensions and replace it with time, we see a conic figure at progressively later times. (Time here is represented as the vertical dimension.) Light emitted at closer and closer distances from the critical event horizon is curved more and more until when emitted from inside this surface, it is curved back toward the center of the body to disappear forever.

Let us look at the fate of matter when subjected to the gravitational collapse of a black hole. Since there exists no known force strong enough to resist the huge gravitational force, matter would continue to be condensed until it approaches a singularity--that is until it has no dimensions and infinite density.

As an illustration of what a black hole would look like both to an observer not caught in its gravitational field and to an observer that is caught in the field, consider the following account written by Kip S. Thorne.

> Once upon a time six ants lived on a large, thin rubber membrane. These ants, being highly intelligent, had developed a way to communicate with one another by means of signal balls that would roll with a constant velocity (the velocity of light) along the surface of the membrane. Unfortunately they had not calculated the strength of the membrane.
>
> One day, five of the ants happened to gather near the center of the membrane and their weight caused it to begin to collapse. The sixth ant--an astronomer ant--was a safe distance away with his signal-ball telescope when the collapse began. The five ants caught in the collapse of the membrane decided to follow it downward rather than try to escape. After the collapse proceeded one of the ants dispatched signal balls in the hope that they would enable the astronomer ant to follow the progress of the collapse.
>
> The collapse of the membrane was characterized by two types of motion. The first was a contraction along the membrane's surface, which, like the gravitational attraction of a star, dragged surrounding objects in toward the center of the collapse. The second was a bending into a sharply curved shape, which, like the space-time curvature in a collapsing star, would eventually crush everything in the region of collapse to infinite density.

The membrane contracted faster and faster as the collapse proceeded. As a result the signal balls, which were sent at equally spaced intervals by the collapsing ants, were received by the astronomer ant at more and more widely spaced intervals (analogous to the reddening of light by an intense gravitational field). Ball No. 15 was sent out 15 minutes after the start of collapse, just as the collapsing ant was sucked past the critical event horizon. It stayed forever at the radius because the membrane at that point was contracting precisely with the speed of the signal. At .001 minutes before reaching the critical event horizon the collapsing ant dispatched ball No. 14.999. This ball, barely outracing the contracting membrane, did not reach the astronomer ant until 122 minutes had passed. Ball No. 15.001, sent out .001 minutes after the critical event horizon was passed, finally got sucked into the singularity.

As seen by the ants inside the collapsing membrane, the collapse ended in a singularity of infinite density after 20 minutes. But as observed by the astronomer ant, whose only information was obtained from the signal balls, the collapse never proceeded beyond the critical event.

Physicists and astronomers are reluctant to accept any theory that predicts a singularity since it violates physical principles. Consequently the explanation is that there must exist some yet undiscovered physical laws that will account for the paradox of the black hole.

This concludes this presentation of the Death of Stars. Perhaps with this explanation and with the knowledge gained during your study of astronomy, you will look at the skies with less wonder. Perhaps, however, these ideas will whet your desire for knowledge to the point that the heavens will now be the origin of even more wonderment. Whatever the case, the universe will continue to be a source of never-ending discovery.

Unit IX--The Milky Way Galaxy

Assignment: Study pp. 181-198; answer the questions on pp. 198-199.

Objectives:

Be able to:

1. Describe the general shape and composition of the Milky Way.
2. Describe roughly the percentages of the various elements in the interstellar medium. Include hydrogen, helium, the remaining 90 elements as a whole, and interstellar dust.
3. Describe how radio astronomers have determined the structure of the Milky Way and how they distinguish among spiral arms.
4. Name and describe two types of star clusters and the part of the Galaxy where each is found; and be able to distinguish between the H-R diagrams of old and young clusters.
5. Describe three differences between population I and population II stars as portrayed on an H-R diagram.
6. Describe three other differences between population I and II stars.
7. Define the following terms:
    1. Milky Way
    2. Galaxy
    3. Interstellar medium
    4. Dust
    5. Blue shift
    6. Red shift
    7. 21-cm. line
    8. Radio astronomy

9. Galactic cluster
10. Open cluster
11. Globular cluster
12. Pleiades
13. Praesepe
14. Population I
15. Population II

Supplementary Information:

Your text mentions the 21-centimeter line of hydrogen in reference to radio astronomy. The question arises as to the origin of the 21-centimeter line. How does hydrogen emit this particular radiation?

Interstellar gas is distributed throughout the regions of the spiral arms of the Galaxy. Hydrogen and helium comprise about 96 to 99 percent of the gas (by mass) with about 75 percent of this being hydrogen.[1]

This hydrogen exists primarily in two forms: ionized hydrogen comprising what are known as H II regions, and neutral (unionized) hydrogen comprising most of what are known as H I regions. H II regions arise when ultraviolet radiation from nearby stars ionizes the hydrogen atoms and helps to create reddish looking nebulae called emission nebulae.

On the other hand, hydrogen atoms that are not ionized make up most of the interstellar hydrogen. These hydrogen atoms are responsible for the 21-centimeter radiation. A neutral hydrogen atom possesses angular momentum by virtue of its electron spin and axial rotation of its proton. When the electron is spinning one direction and the proton is spinning in the opposite direction, the atom is in a slightly lower energy state than if they were both spinning in the same direction. Ordinarily a hydrogen atom is in the lowest state. However, it can be raised to the higher state by a collision with an electron. These collisions are very rare though, due to the very low density of gases in interstellar space. Millions of years may pass before such a collision would occur. Nevertheless, over many millions of years, a large part of these atoms are thus excited.

Now a hydrogen atom can revert to its lower state either by a subsequent collision or by a spontaneous reversal of the nuclear spin. The latter results in the radiation of a photon of 21-centimeter wavelength.

It is interesting to note that an excited atom may wait, on the average, some 10 million years before emitting a photon and returning to its lowest state.[2] But enough atoms are radiating photons of 21-centimeter wavelength to make radio observation possible.

Additional Reading for Interested Students:

Bok, Bart J. "Spiral Structure of Our Galaxy - I," *Sky and Telescope*, XXXVIII (December, 1969), 392-95; and "Spiral Structure of Our Galaxy - II," *Sky and Telescope*, XXXIX (January, 1970), 21-25.

---

[1]George Abell, *Exploration of the Universe* (2nd ed.; New York: Holt, Rinehart and Winston, 1969), p. 512.

[2]*Ibid.*, p. 518.

Unit X--Galaxies

<u>Assignment</u>: Study pp. 201-216; answer the questions on pp. 216-217.

<u>Objectives</u>:

Be able to:

1. Draw the two extremes of each of the three "regular" types of galaxies and label each according to Hubble's classification.
2. State the percentage abundance of each of the three major types of galaxies and classify each as to their relative size, existence of gas and dust, and whether they have mostly old or young stars, or both.
3. Describe a fourth type of galaxy--the irregular--as to mass and relative age of its stars.
4. Describe the formation of galaxies. Include as stages: protogalaxies, galaxies, and possible death formations.
5. Explain one reason each why Hubble's theory of galactic evolution and the reverse theory cannot be true.
6. State an explanation for the spiral, elliptical, and barred spiral shapes.
7. State two possible reasons for "peculiar galaxies."
8. Define the following terms:

    1. Elliptical galaxy
    2. Spiral galaxy
    3. Barred spiral galaxy
    4. Irregular galaxy
    5. Magellanic Cloud
    6. Protogalaxy
    7. Density pattern
    8. Peculiar galaxies
    9. Normal galaxies

Supplementary Information:

THE SUN AND OUR LIVES

Perhaps with this unit on galaxies, due to the fact galaxies are made up primarily of stars, we should look back on our small contribution to the Milky Way galaxy--the sun. The origin of the sun and its system of planets along with the origin of life will be the subject of the last section of your text. But what is the source of life as it exists today on earth? The answer is the sun.

Let us take a short look at the influence of the sun on our lives. To begin with, all life on the earth depends on the sun for heat and light. If this source were to change or become inconsistent, life would be in great peril. Too much or too little heat and light could change life processes radically. This can be seen in plant life for example, with the relatively minor seasonal changes that occur on the earth.

Furthermore, life depends on the sun for food. All living things are part of a process called the food chain. Plants make their food through photosynthesis. Plants combine carbon dioxide from the air and water from the soil with energy from the sun to make food, giving off oxygen in the process. Animals will eat plants. In turn, these animals are eaten by other animals. Man eats both plants and animals. Man and animals inhale oxygen from the plants and exhale carbon dioxide which is used by plants. The cycle continues.

The sun is a further energy source. Prior to the development of nuclear energy, life depended on the sun exclusively for energy. Besides food, plants and animals were used for clothing and shelter. More indirectly, however, larger energy sources attributed to the sun are the fossil fuels. These include coal, oil, and natural gas and are derived from organisms that lived millions of years ago. By burning these fuels, man releases energy from the sun that was stored beneath the earth's surface for all those years. More directly, energy sources resulting from sunlight include solar batteries and solar furnaces.

The sun's energy is also manifested in the weather phenomena on the earth. The sun causes evaporation of water, which results in rain and snow. Water vapor forms clouds which both keep heat from the sun away from the earth's surface and keep heat from the earth's surface from escaping into the atmosphere. Because of the inclination of the earth's axis, the sun's rays hit the earth at different angles. This, along with clouds, causes uneven heating and results in differences in air pressure. Hence winds and changes in temperature occur. Winds can be used as an energy source in powering windmills. Rains result in rivers which can be used in developing hydroelectric power.

Beyond these energy sources and weather phenomena, the sun has been used since ancient times as a timekeeper. The length of the day and year are directly attributed to the sun. Ancients used sundials for daily time. Some ancient calendars were based on the moon's phases, which result from reflected sunlight as the moon revolves around the earth. The sun is further used, along with time, by navigators and surveyors to tell direction and position.

Finally the aesthetic values of the sun influence our daily perceptions. Whenever we have a beautiful day, it is usually because the sun's light and heat are in evidence. Who has not commented on a beautiful sunset? The phenomenon of the aurora is a most beautiful and spectacular display. It is the result of particles from the sun colliding with particles in the earth's atmosphere.

Artists, authors, and musicians have utilized the beauty of the sun in their work. Emily Dickenson wrote a poem describing the rising and setting, called appropriately, "The Sun." Van Gogh created many landscapes expressing his joy with bright sunshine. And Rimsky-Korsakov included the beautiful "Hymn to the Sun" in his opera <u>The Golden Cockerel</u>.

Both in beauty and in necessary life-giving energy, the sun has probably the most profound single influence on our daily lives.

<u>Note</u>: For an in-depth and very interesting article on the sun, read "Our Life-Giving Star, the Sun" in the November, 1965, issue of <u>National Geographic</u>. Easily read and vividly illustrated, this Herbert Freedman piece discusses the energy source, evolution, and life-giving aspects of this vital star.

Unit XI--Radio Galaxies, Seyfert Galaxies, and Quasars

Assignment: Study pp. 219-237; answer the questions on pp. 237-238.

Objectives:

Be able to:

1. Describe the two differences between normal galaxies and abnormal galaxies with respect to energy emission.
2. Describe the visual characteristics of two different-appearing radio galaxies.
3. Explain, by the tentatively accepted hypothesis described in your text, the twin-lobed appearance of radio galaxies.
4. Explain the possible source of radio waves in a radio galaxy.
5. Compare Quasars, Seyfert Galaxies, and Normal Galaxies with respect to size, brightness, spectrum, and visual appearance, and compare Quasars and Seyferts as to their radio pictures.
6. Describe the factors that led to the discovery of Quasars, and why these objects could not be single stars.
7. Describe both the supernova theory and the "giant pulsar" theory of energy production in Quasars.
8. Define the following terms:

1. Normal galaxy	4. Seyfert galaxies
2. Radio galaxies	5. Quasar
3. Abnormal galaxies	6. Radio stars

7. Quasi-Stellar Sources (QSS)
8. Quasi-Stellar Objects (QSO)
9. Gravitational red shift
10. Anti-matter
11. Antiproton
12. Antielectron
13. Positron

Supplementary Information:

Quasars are among the most interesting objects yet discovered in the universe. They appear to travel at phenomenal speeds, have huge energy generating capacities, and are the most distant objects yet discovered. The understanding of their origin and properties may well unlock the deepest secrets of creation and evolution. Below are listed some interesting articles on Quasars that expand on the material presented in your text.

Burbridge, Geoffrey, and Fred Hoyle. "The Problem of the Quasi-Stellar Objects," Scientific American, CCXV (December, 1966), 40-52. (Maintains that there exists no hypothesis that explains QSO's.)

Green, Louis C. "Quasars Six Years Later," Sky and Telescope, XXXVII (May, 1969), 290-294. (A look at quasars and the development of knowledge of them six years after their discovery.)

Burbridge, E. Margaret, and C. Roger Lynds. "The Absorption Lines of Quasi-Stellar Objects," Scientific American, CCXXIII (December, 1970), 22-29.

Schmidt, Martin, and Francis Bello. "The Evolution of Quasars," Scientific American, CCXXIV (May, 1971), 54-69.

Unit XII--Cosmology

Assignment: Study pp. 241-256; answer the questions on pp. 256-257.

Objectives:

Be able to:

1. Define "cosmology."
2. Explain how observations show that hydrogen is disappearing from the universe.
3. Describe the cosmological significance of the life story of stars.
4. Describe the "Big-Bang" cosmology with respect to the beginning, present, and future of the universe.
5. Describe the "Steady-State" universe and the principle of science that it apparently violates.
6. Describe the "Oscillating Universe" and compare it with the "Big-Bang" theory.
7. State Hubble's Law and explain what it means.
8. Describe how, using the Hubble Law, it is theoretically possible to test each of the three mentioned cosmologies.
9. Describe, assuming either Oscillating or Big-Bang is correct, a method of testing the two cosmologies (other than Sandage's theory).
10. Define the following terms:

1. Big-Bang Universe	4. Hubble constant
2. Ylem	5. Primordial Fireball
3. Steady-State Universe	6. Gravity Waves

Supplementary Information:

Cosmology is defined as the study of the organization and evolution of the universe. This subject has occupied the minds of everyone that has ever lived. There are and have been many ideas throughout history as to the origin of the universe. They have included religious creation, modern cosmological ideas, and as you may expect, pure fantasy and science fiction. Your text discusses three currently held theories: the Big-Bang, Oscillating Universe, and Steady-State Universe. These are relatively modern theories and are still being tested. As an extension of the last three units on galaxies and quasars, there is a film that will be shown in the planetarium during this unit. It is a 14-minute film entitled "Space Science: Galaxies and the Universe." It reviews the various types of galaxies, illustrates quasars and population I and II stars, and discusses the three above-mentioned cosmological theories.

In addition, there are two articles in Sky and Telescope on cosmology that are well worth reading. The first is a two-part series appearing in the January and February, 1965, issues. It is called "The Evolution of Galaxies" and is written by Thornton L. Page. The second, authored by Louis C. Green, appears in the April, 1966, issue. It is entitled "Observational Aspects of Cosmology" and describes methods of testing cosmological theories--an expansion of those methods discussed by Jastrow.

<u>To the Instructor</u>: "Space Science: Galaxies and the Universe" is available for renting from the Film Center of Syracuse University, Syracuse, New York.

Unit XIII--The Solar System

Assignment: Study pp. 261-288; answer the questions on p. 289.

Objectives:

Be able to:

1. Describe the Condensation Theory of formation of our solar system and draw a conclusion about another solar system from this theory.
2. Describe the method stated in your text of detecting planets revolving around stars (other than direct observation).
3. State three arguments in favor of the Condensation Theory and three objections to the theory.
4. State one possible reason why the terrestrial planets are nearly void of hydrogen and helium, while the larger planets are not.
5. State the "inverse-square law of gravity."
6. Explain the differences in temperature and density between the terrestrial planets and the giant planets.
7. Explain the rings of Saturn using the Roche limit concept.
8. Describe the orbital characteristics of asteroids and comets and compare their sizes with those of meteorites.
9. Define the following terms:
    1. Condensation Theory
    2. Solar System
    3. Comet
    4. Momentum
    5. Gravity
    6. Law of Gravity

7. Astronomical Unit
8. Ecliptic
9. Planet's year
10. Planet's day
11. Terrestrial Planets
12. Roche limit
13. Asteroid
14. Meteorites
15. Chrondrite

Supplementary Information:

The early history of astronomy is primarily centered around the solar system. The ancients probably viewed the skies in wonder pretty much the same as most people do today. As time passed many theories and explanations were advanced for that which was observed. Not until Copernicus' time, however, were currently held explanations of the solar system in existence. Shortly following Copernicus, many revolutionary discoveries were made. Among these were the laws of planetary motion advanced by Johannes Kepler. There are two articles that are of interest in describing how Kepler came to making his discoveries. The first was published in the December, 1971, issue of Sky and Telescope, and is entitled "Johannes Kepler and Rudolphine Tables." It is authored by Owen Gingerich. Further history of Kepler's discoveries is related in a Scientific American article of March, 1972, called "How Did Kepler Discover His First Two Laws?" by Curtis Wilson. Both of these are well written and informative.

To the Instructor: A planetarium program depicting the motions of the planets would be appropriate during this unit. Topics to include should be retrograde motion, relative size of the planets and their orbits, visual aspects of each planet, and viewing the planets as they appear to move through the stars as seen from the earth.

Unit XIV--The Earth

Assignment: Study pp. 291-311; answer the questions on p. 311.

Objectives:

Be able to:

1. Diagram the interior of the earth to show the three major parts in relative proportion and composition.
2. Describe radioactive decay and explain how it heats the interior of the earth.
3. Explain differentiation of the earth's interior as a process in which the core, mantle, and crust were formed.
4. Explain why the rarest elements in the cosmos are found in much larger relative abundance in the crust of the earth.
5. Explain how continents drift and how this is probably the main reason for earthquakes and the creation of mountain ranges.
6. State two pieces of evidence that South America and Africa were once one land mass.
7. Describe what "moves" the continents.
8. Define the following terms:
    1. Sedimentary rock
    2. Igneous rock
    3. Core
    4. Mantle
    5. Crust
    6. Continental Drift
    7. Radioactive elements
    8. Differentiation
    9. Granite
    10. Quartz
    11. Orthoclase feldspar
    12. Pyroxine

13. Olivine
14. Plagioclase feldspar
15. Tetrahedron
16. Zone of Weakness
17. Continental roots
18. Plates
19. Earthquakes
20. Island arc
21. Mid-Atlantic Ridge
22. Gonduanaland
23. Laurasia
24. Tethys Sea
25. Convection currents

Supplementary Information:

Your text describes the modern theory of the structure of the earth and the related topics such as continental drift. For an updated view of this theory including descriptions of tests in support of the theory, read "The Changing Earth" in the January, 1973, issue of National Geographic. In the same issue is a related article called "California's San Andreas Fault." It attempts to explain the countless number of earthquakes that occur in that region of the country and why many people think that much of California will break off and slide into the sea.

Unit XV--The Moon

Assignment: Study pp. 313-330; answer the questions on p. 330.

Objectives:

Be able to:

1. Explain why the surface of the earth is different from the surface of the moon.
2. Describe micrometeorite erosion on the moon and name two of its by-products. Furthermore, explain why micrometeorite erosion is not in evidence on the earth.
3. Explain why there exists no air or water on the moon.
4. Explain why there exists no life on the moon today, but how something may exist on the moon to indicate the origin of life.
5. State two pieces of evidence that there once was volcanic activity on the moon and three pieces of evidence that today the moon is cold.
6. Describe one theory on the evolution of the structure of the moon.
7. Explain the importance of moon exploration with respect to the history of the earth.
8. Define the following terms:

    1. Micrometeorites
    2. Maria
    3. Amino acids
    4. Nucleotides
    5. Hyginus Rille
    6. Marius Hills
    7. Hadley Rille
    8. Mascons
    9. Seismometer
    10. Lunar Orbiter

Supplementary Information:

Neil Armstrong set foot on the moon in July, 1969. Of course you all know that. But what many of you may not have been aware of was all the preparation involved to achieve that historic landing. Besides all the technical research with respect to rockets, physiology, physics, and the like, astronomers also had a large part in the moon landing project.

A welcome result of putting a man on the moon was a vast amount of knowledge gained in the process. Much of the information contained in your text is derived from the preparation and the actual landing. Another example of this kind of offshoot is an extremely accurate map of the surface of the moon.

For an interesting and enlightening article on the construction of this map, along with some excellent background information on the preparation for man's first journey to the moon, read "The Moon" and "How We Mapped the Moon" in the February, 1969, issue of National Geographic.

Unit XVI--Venus, Mars, Jupiter

Assignment: Study pp. 333-358; answer the questions on p. 358.

Objectives:

Be able to:

1. Describe the structure, revolutionary period, and visual appearance (general) of Venus.
2. Explain how Radio astronomers determined the temperature of Venus to be 800° F.
3. Describe three results of the American and Russian Venus probes.
4. Explain the Greenhouse effect and how it affects the temperature on Venus.
5. Describe Mars', Venus', and Jupiter's size and orbit as compared with the earth.
6. Explain the main reason why life on Mars is not likely, but why it may have supported life in the past.
7. Describe the Radioactive Carbon test for life on Mars, along with the methane and nitrogen gas tests. Include possible sources of methane and nitrogen on the planet.
8. Explain why Jupiter is a planet and not a star.
9. Describe the structure of Jupiter (three main layers) and the reasons for the state of each layer.
10. Define the following terms:
    1. Retrograde rotation
    2. Micron
    3. Greenhouse Effect
    4. Hellas

<u>Supplementary Information</u>:

There are many theories today that attempt to explain the things we observe in the universe. Because of the vast distances and limitations of time and technology, many times it is impossible to test these theories by observation. For instance, stellar evolution and the apparent movements with respect to the Hertzsprung-Russell diagram are theories that appear to be valid. However, direct observation of the entire lifetime of the different types of stars is impossible due to the length of time involved.

With modern technology and space travel today, many of the theories and ideas about our solar system are being tested by direct observation. An example of this is the Mariner series of space probes, specifically Mariner 9 and its trip to Mars in 1971. <u>National Geographic</u> published an excellent article on the method and results of this historic space probe in the February, 1973, issue of the magazine. It is called "Journey to Mars," and I recommend you read it.

Unit XVII--The Earth and Venus--A Study in Contrasts

Assignment: Study pp. 361-369; answer the questions on p. 370.

Objectives:

Be able to:

1. Explain why the Earth and Venus could, in the beginning, have been expected to have the same constituents in their atmospheres and describe one mechanism in which primitive atmospheres may have been lost.
2. Explain from where the present atmospheres of Venus and the Earth emerged.
3. Explain why the earth's atmosphere did not become as concentrated with carbon dioxide as that of Venus.
4. Describe what factor is responsible for the presence of oxygen on the earth.
5. Explain the difference in the amount of water and water vapor on Venus and earth.
6. Describe three reasons why Mars, in view of the evolutionary processes on Venus and the earth, does not have conditions favorable to life as we know it.
7. Define the following terms:
    1. Photodissociation
    2. Runaway Greenhouse effect

Supplementary Information:

Venus has been called the earth's sister planet because of their many similarities. Exploration of Venus through space probes and other modern astronomical innovations has shown that Venus is indeed very much different from the earth. Jastrow points out many of these differences in the text. A February, 1971, article in Sky and Telescope entitled "The Exploration of Venus" describes in detail the Soviet and United States space probes to the mysterious planet. It is an expansion of many of the ideas mentioned in the text and I recommend its reading.

In addition, a 29-minute film called "Clouds of Venus" will be shown in the planetarium during this unit. It is the story of the United States' Venus probe, Mariner II.

To the Instructor: "Clouds of Venus" is available for renting from the Visual Aids Service, University of Illinois, Champaign, Illinois.

Unit XVIII--Life in the Cosmos

Assignment: Study pp. 373-391; answer the questions on pp. 391-392.

Objectives:

Be able to:

1. State three facts that support the hypothesis that life evolved spontaneously from chemicals existing on the earth in its infancy.
2. Describe a process in which ammonia, methane, water vapor, and hydrogen could have evolved into life. Include their conversion into amino acids.
3. Describe why certain stars would be suitable to the evolution of life while others are not.
4. State a logical three-step argument supporting the belief that life similar to life on earth can exist elsewhere in the cosmos.
5. Explain Natural Selection and the most important factor that supports or lends credence to Darwin's theory.
6. State simply the evolution of life, according to Darwin, from the simplest algae to present man.
7. Define the following terms:

    1. Amino Acids
    2. Nucleotides
    3. Proteins
    4. Building Blocks of Life
    5. DNA
    6. Virus
    7. Electron Microscope
    8. Natural Selection

<u>Supplementary Information</u>:

Life as we know it almost certainly does not exist elsewhere in our solar system. But assuming that modern ideas of star formation are true and realizing the existence of huge numbers of stars and galaxies in the universe, it seems impossible that earth is the only place where life exists. As with Darwin's theory, time is on the side of this form of evolution. In line with this, a 29-minute film entitled "Invisible Planet" will be shown in the planetarium during this unit. Produced by National Educational Television, the film describes van de Kamp's study of the universe in search of life. In particular, it shows techniques used to study the wobble of Barnard's star. It proves the existence of an unseen planet and supports the aforementioned theory of life in the universe.

In further support of this theory of life is the June, 1972, <u>Scientific American</u> article called "Organic Matter in Meteorites." Authored by James G. Lawless and Clair E. Folsome, it describes studies of organic matter found in meteorites that are not of biological origin.

<u>To the Instructor</u>: "Invisible Planet" is available for renting from the Film Center of Syracuse University, Syracuse, New York.

SAMPLE EXAMINATIONS

To the Instructor: A sample examination has been written for each unit. Each examination contains five questions. Three to four of these questions can be answered with a word, phrase, or short sentence. The remaining one or two questions are designed to require a more lengthy answer. Examples of the latter include questions requiring a three or four sentence explanation or a diagram. All of the questions are based directly on the objectives listed with each unit.

Unit I

1. What significant change to Ptolemy's theory did Copernicus make in his attempt to explain the motions of the planets?
2. State a proof that the earth revolves around the sun.
3. Draw a face-on diagram, including the earth, moon, and sun, of a lunar eclipse and name the phase of the moon during this eclipse.
4. Draw a face-on diagram of the earth, moon, and sun during a neap tide.
5. Define right ascension.

Unit II

1. Draw a diagram of the earth, sun, and stars to explain why we see different stars at night in December than we see in June.

2. What motion of the earth makes the stars appear to move across the sky and why does Polaris not have the same kind of motion?
3. Explain the difference between an optical double and a binary star.
4. Name the three fundamental forces that hold the universe together, starting with the least powerful and ending with the most powerful.
5. (In the planetarium) Use the arrow flashlight to identify six constellations in the current sky along with one star in each.

<u>Unit III</u>

1. What property of light allows it to travel through space?
2. What is the primary difference between visible light and radio waves?
3. Find the wavelength of an electromagnetic wave traveling at the speed of light (186,000mps) with a frequency of 10,000,000cps.
4. Define Doppler shift and tell whether an object moving away from an observer would be red-shifted or blue-shifted.
5. What factor determines at which wavelength an object radiates most of its energy?

Unit IV

1. Draw a diagram of a refracting telescope and identify the parts. (Include all parts necessary for a viewer to be able to see an image.)
2. Why will a 40-inch refractor enable a viewer to see more detail in a celestial object than a 5-inch refractor?
3. What is the difference between a Cassegrain reflector and a Newtonian reflector (two differences)?
4. Why can people not see an image by looking at an object with a radio telescope?
5. What property of light allows a prism spectrograph to work?

Unit V

1. If the element iron were present on a certain star, how could an astronomer detect it?
2. If a photon is absorbed by an atom, what kind of line would be visible in its spectrum? (bright or dark)
3. Describe what happens when an atom becomes excited.
4. List the seven classifications of stellar spectra in order of increasing temperature.
5. Which would have a broader line in a spectrum, Titanium Oxide or Iron?

Unit VI

1. Which star has the highest surface temperature, a red giant or a yellow main sequence star?
2. Define the term "main sequence."

3. What is the most significant factor that determines a star's position on the main sequence?
4. Which star has evolved further in its stellar life, a red giant or a white dwarf?
5. Describe a Cephied variable in terms of brightness.

Unit VII

1. Why can nuclear fission not be the prime source of energy in stars?
2. Why have we not been able to harness nuclear fusion as a source of power on the earth?
3. What is the source of the energy released during a nuclear reaction?
4. What is the probable origin of the heavy elements found on the earth?
5. What is the single most important factor that leads to the temperatures necessary to support nuclear fusion in stars?

Unit VIII

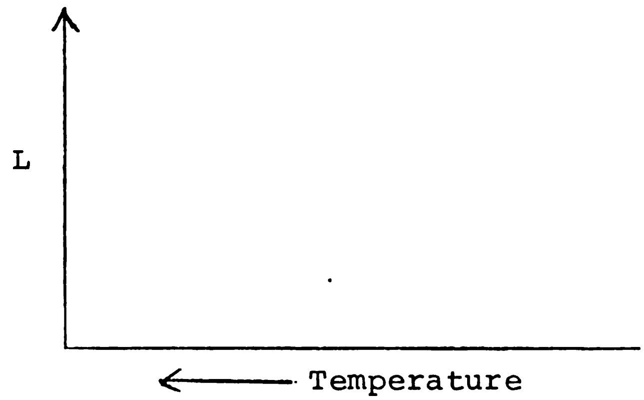
1. What force is primarily responsible for the collapse of gas clouds that form stars?
2. What is the source of the initial temperature rise in a protostar?
3. What reaction dominates the major portion of the life-span of a star?
4. About what percentage of a star's life is spent on the main sequence?

5. Draw an H-R diagram tracing the life of a star from a gas cloud to a white dwarf.

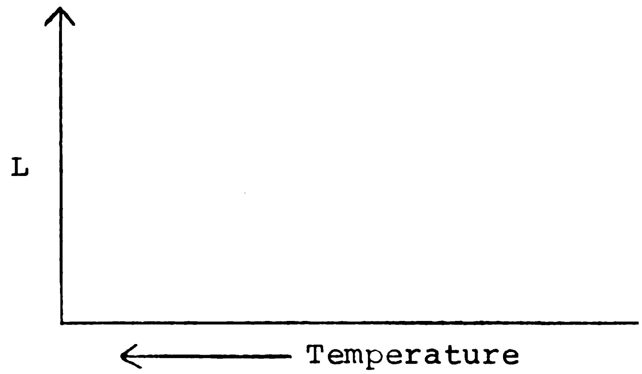
Unit IX

1. Draw an edge-on and a face-on diagram of the Galaxy.
2. What is the main constituent of the interstellar medium and what percentage of the medium is it? What is the next most abundant substance?
3. Define the 21-centimeter line.
4. What phenomenon allows radio astronomers to distinguish among spiral arms in the Galaxy?
5. Which of the following star clusters depicted on an H-R diagram is most probably a globular cluster and why?

(a)



(b)



Unit X

1. Draw an edge-on view of the two extremes of elliptical galaxies and label each as either E-O or E-7.
2. Describe the difference (by a diagram if you like) between Spiral galaxies and Barred spirals.
3. List the three regular types of galaxies in order of increasing percentage occurrence in the universe.
4. Explain what factor could account for the different shapes of elliptical galaxies (according to Jastrow).
5. The appearance of peculiar galaxies was apparently the result of one of two events. Name these two events.

Unit XI

1. What are the two main differences between normal and abnormal galaxies?
2. What is the currently held reason for the appearance of a radio galaxy?
3. Explain what produces the radio-wave emission in a radio galaxy.
4. Describe two distinguishing features of a Seyfert galaxy.
5. Describe a quasar as to its visual appearance and its most distinguishing feature.

Unit XII

1. Define cosmology.
2. What happens in each star to support cosmologists' beliefs that hydrogen is disappearing from the universe?

3. According to the Big-Bang theory, what is the future of the universe? (i.e.: What will eventually become of the universe?)
4. What is the advantage the Oscillating theory has over the Big-Bang theory?
5. Why must the Hubble constant be the same throughout time according to the Steady-State theory?

Unit XIII

1. Would it have been possible to form an earth-like planet around a population II star? Why or why not?
2. What was observed about Barnard's star that suggested the existence of a planet?
3. Why do the rings of Saturn not fall into the planet?
4. Why does the existence of a significant atmosphere on Pluto not seem likely?
5. An object the size of the moon, but three times as far from the earth as the moon, will experience what fraction of the gravitational force exerted by the earth on the moon?

Unit XIV

1. What is the composition of the earth's mantle and what is its physical state?
2. Define differentiation as it applies to the earth's structure.
3. Cite two reasons why geologists believe South America and Africa were once joined together.

4. Account for the formation of the Himalayan mountains.
5. Why is it that the earth contains a greater percentage of uranium than is found in the cosmos?

Unit XV

1. Why are there more craters on the moon than on the earth?
2. Why is micrometeorite erosion not in evidence on the earth?
3. What could exist on the moon to aid in discovery of the origin of life?
4. Account for the fact that there is no water on the moon.
5. What evidence supports the idea that the Hyginus Rille was the scene of volcanic activity?

Unit XVI

1. Compare the four primary phases of Venus with the moon by stating relative positions of each with respect to the sun and earth. (A diagram might be helpful.)
2. What would be a possible source of methane if it existed on Mars?
3. List two important results of the Russian Venus probe with respect to the atmosphere of the planet.
4. Why is Jupiter a planet and not a star?
5. Define Greenhouse effect and explain how it is applicable to Venus.

Unit XVII

1. Give one possible explanation for the loss of primitive atmospheres on Venus and earth.
2. From where did the present constituents of the earth's and Venus' atmospheres come?
3. Explain the low percentage of carbon dioxide in the earth's atmosphere.
4. Why is there so little water on Venus?
5. In view of your answer to question 4, why is there a large amount of water on the earth?

Unit XVIII

1. State three facts that support the hypothesis that life evolved from chemicals existing on the earth at its infancy.
2. Describe a process in which amino acids could be produced from the gasses in a primitive atmosphere.
3. What factor is the most important supportive factor for Darwin's theory of evolution?
4. Define "Natural Selection."
5. What is the number of the final unit test?

REFERENCE MATERIAL

Part I:

The material listed below is included as additional reference material for the applicable units of instruction. A survey of each issue of Scientific American, Sky and Telescope, and National Geographic published during the last ten years was made. Articles listed were deemed to be of a conceptual nature and not difficult to read.

I suggest that this section be used for those students seeking material beyond that which is presented in the supplementary information. Material listed there is not listed again. In addition, material listed here will not be included again in the bibliography.

UNIT I:

Ravetz, J. E. "The Origins of the Copernican Revolution," Scientific American, CCXV (October, 1966), 88-98.

Leavitt, I. M., and Roy K. Marshall. Star Maps for Beginners. New York: Simon and Schuster, 1964.

Olcott, William. Field Book of the Skies. Revised and edited by R. Newton and Margaret W. Mayall. New York: G. P. Putnam's and Sons, 1954.

UNIT II:

Lippincott, Sarah Lee, and Michael D. Worth. "The Double Star Sirius," Sky and Telescope, XXXI (January, 1966), 4-6.

Moskowitz, Saul. "Visual Aspects of Trans-Stellar Space Flight," Sky and Telescope, XXXIII (May, 1967), 290-294.

Norton, O. Richard. "Thoughts About Constellation Figures," Sky and Telescope, XXX (October, 1965), 203-205.

UNIT III:

Feinberg, Gerald. "Particles That Go Faster Than Light," Scientific American, CCXXII (February, 1970), 68-77.

Ginzburg, V. L. "The Astrophysics of Cosmic Rays," Scientific American, CCXX (February, 1969), 50-63.

Sharkland, R. S. "The Michelson-Morley Experiment," Scientific American, CCXI (November, 1964), 107-114.

Weisskoph, Victor F. "How Light Interacts With Matter," Scientific American, CCXIX (September, 1968), 60-71.

UNIT IV:

"Arecibo Observatory Today," Sky and Telescope, XLIII (April, 1972), 214-217, 228.

Goldberg, Leo. "Ultraviolet Astronomy," Scientific American, CCXX (June, 1969), 92-102.

"The Latest Flight of Stratoscope II," Sky and Telescope, XXXIX (June, 1970), 365-367.

Lutsky, Valery. "The 236-inch Soviet Reflector," Sky and Telescope, XXXIX (February, 1970), 99.

Lovell, Sir Bernard. "Radio Emitting Flare Stars," Scientific American, CCXI (August, 1964), 13-19.

Stewart, Albert B. "The Discovery of Stellar Aberration," Scientific American, CCX (March, 1964), 100-108.

Wells, R. A. "The First Newtonian," Sky and Telescope, XLII (December, 1971), 342-344.

Young, Andrew T. "Seeing and Scintillation," Sky and Telescope, XLII (September, 1971), 139-141, 150.

UNIT V:

Anderson, Dean H. "The Stars of Very Large Proper Motion," Sky and Telescope, XXXVIII (August, 1969), 76-78.

Connes, Pierre. "How Light Is Analyzed," Scientific American, CCXIX (September, 1968), 72-82.

Giordaime, J. A. "The Interaction of Light With Light," Scientific American, CCX (April, 1964), 38-49.

Greenberg, J. Mayo. "Instellar Grains," Scientific American, CCXVII (October, 1967), 106-114.

Neugebauer, G. and Robert B. Leighton. "The Infrared Sky," Scientific American, CCXIX (August, 1968), 50-65.

UNIT VI:

Batten, Alan H., and Miroslav Plavec. "Two New Chapters in the Story of U. Cephei," Sky and Telescope, XLII (September, 1971), 147-150.

Iben, Icko, Jr. "Globular Cluster Stars," Scientific American, CCXXIII (July, 1970), 26-39.

UNIT VII:

Dyson, Freeman J. "Energy in the Universe," Scientific American, CCXXV (September, 1971), 50-59.

UNIT VIII:

Aller, Lawrence H. "The Planetary Nebulae," Sky and Telescope, XXXVII (May, 1969), 282-286.

Bok, Bart J. "The Birth of Stars," Scientific American, CCXXVII (August, 1972), 48-61.

Bok, Mart J. "The Gum Nebula," Sky and Telescope, XLII (August, 1971), 64-69.

Boyco, Anatole. "Inside a Globular Cluster," Sky and Telescope, XXVIII (March, 1964), 269-272.

Cameron, A. G. W., and Stephen P. Moran. "The Enigmatic Pulsars--Facts and Interpretation," Sky and Telescope, XXXVI (July, 1968), 4-9.

Eggen, O. J. "Stars in Contact," Scientific American, CCXVII (June, 1968), 34-40.

Friedman, Herbert. "X-Ray Astronomy," Scientific American, CCX (June, 1964), 36-45.

Giacconi, Riccardo. "X-Ray Stars," Scientific American, CCXVII (December, 1967), 36-45.

Gorenstein, Paul, and Wallace Tucher. "Supernova Remnants," Scientific American, CCXXV (July, 1971), 74-85.

Green, Louis C. "Pulsars Today," Sky and Telescope, XL (November, 1970), 260-262.

Green, Louis C. "Relativistic Astrophysics," Sky and Telescope, XXIX (March, 1965), 145-148.

Hack, Margherita. "Late-Type Stars," Sky and Telescope, XXXIII (February, 1967), 74-76.

Herbig, George H. "The Youngest Stars," Scientific American, CCXVII (August, 1967), 30-36.

Hewish, Antony. "Pulsars," Scientific American, CCXIX (October, 1968), 25-35.

Huang, Su-Shu. "The Origin of Binary Stars," Sky and Telescope, XXXIV (December, 1967), 368-370.

Kumar, Shiv S. "Stars of Low Luminosity," Sky and Telescope, XXXVI (August, 1968), 82-84.

Neugebauer, G., and Eric E. Becklin. "The Brightest Infrared Sources," Scientific American, CCXXVIII (April, 1973), 98-105.

Ostriker, Jeremiah P. "The Nature of Pulsars," Scientific American, CCXXIV (January, 1971), 48-60.

Placini, Franco, and Martin J. Rees. "Rotation and High-Energy Astrophysics," Scientific American, CCXXVIII (February, 1973), 98-105.

Penrose, Roger. "Black Holes," Scientific American, CCXXVI (May, 1972), 38-46.

Ruderman, Malvin A. "Solid Stars," Scientific American, CCXXIV (February, 1971), 24-31.

Thorne, Kip S. "Gravitational Collapse," Scientific American, CCXVII (November, 1967), 88-98.

Weber, Joseph. "The Detection of Gravitational Waves," Scientific American, CCXXIV (May, 1971), 22-29.

UNITS IX AND X:

Arp, Halton. "On the Origin of Arms in Spiral Galaxies," Sky and Telescope, XXXVIII (December, 1969), 385-387.

Bok, Bart J. "The Large Cloud of Magellan," Scientific American, CCX (January, 1964), 32-41.

Hodge, Paul W. "Dwarf Galaxies," Scientific American, XLIV (May, 1964), 78-86.

Hodge, Paul W. "The Sculptor and Formax Dwarf Galaxies," Sky and Telescope, XXVII (December, 1964), 336-339.

Hodge, Paul W. "Some Current Studies on Galaxies," Sky and Telescope, XLIV (July, 1972), 23-27.

Lynds, Beverly T. "Spiral Patterns in Galaxies," Sky and Telescope, XXXIII (June, 1967), 343-346.

"Maffei I: A New Nearby Galaxy," Sky and Telescope, XLI (March, 1971), 144-145.

Rees, Marin J., and Joseph Silk. "The Origin of Galaxies," Scientific American, CCXXII (June, 1970), 26-35.

Sandage, Allan R. "Exploding Galaxies," Scientific American, CCXI (November, 1964), 38-47.

Westerlund, Bengt E. "Report on the Magellanic Clouds," Sky and Telescope, XXXVIII (July, 1969), 23-27.

UNIT XI:

Kellermann, K. I. "Intercontinental Radio Astronomy," Scientific American, CCXXVI (February, 1972), 72-83.

"The Remotest Objects Ever Identified," Sky and Telescope, XXX (July, 1965), 16.

Weymann, Ray J. "Seyfert Galaxies," Scientific American, CCSS (January, 1969), 28-37.

UNIT XII:

Alfven, Hannes. "Antimatter and Cosmology," Scientific American, CCXVI (April, 1967), 106-114.

Feinberg, Gerald. "Ordinary Matter," Scientific American, CCXVI (May, 1967), 126-134.

Huang, Su-Shu. "Recent Findings About Early Solar System History," Sky and Telescope, XXVIII (July, 1964), 13-15.

Peebles, P. J. E., and David T. Wilkenson. "The Primeval Fireball," Scientific American, CCXVI (June, 1967), 28-37.

UNIT XIII:

"The Composition of Saturn's Rings," Sky and Telescope, XXXIX (January, 1970), 14.

Cruikshank, Dale P., and Clark R. Chapman. "Mercury's Rotation and Visual Observations," Sky and Telescope, XXXIV (July, 1967), 24-26.

Guerin, Pierre. "The New Ring of Saturn," Sky and Telescope, XL (August, 1970), 88.

Rawlins, Dennis. "The Mysterious Case of the Planet Pluto," Sky and Telescope, CCXIX (July, 1968), 160-162.

Shapiro, Irwin I. "Radar Observations of the Planets," Scientific American, CCXIX (July, 1968), 28-37.

Weaver, Kenneth F. "Voyage to the Planets," National Geographic, CXXXVIII (August, 1970), 147-193.

UNIT XIV:

Anderson, Don L. "The San Andreas Fault," Scientific American, CCXXV (November, 1971), 52-68.

Bolt, Bruce A. "The Fine Structure of the Earth's Interior," Scientific American, CCXXVIII (March, 1973), 24-33.

Barnea, Joseph. "Geothermal Power," Scientific American, CCXXVI (January, 1972), 70-77.

Dewey, John F. "Plate Tectonics," Scientific American, CCXXVI (May, 1972), 56-68.

Donn, William L. "Causes of the Ice Age," Sky and Telescope, XXXIII (April, 1967), 221-225.

"An Ecology Satellite Eyes the Earth," Sky and Telescope, XLVI (September, 1972), 151-153.

Hallam, A. "Continental Drift and the Fossil Record," Scientific American, CCXXVII (November, 1972), 56-66.

Herley, Patrick M. "The Confirmation of Continental Drift," Scientific American, CCXVII (April, 1968), 52-64.

Lowman, Paul D. "New Knowledge of Earth From Astronauts' Photographs," National Geographic, CXXX (November, 1966), 645-671.

UNIT XV:

"Apollo 16 Brings Us Visions From Space," National Geographic, CXLII (December, 1972), 856-865.

"Findings From Sample Lunar Material," Sky and Telescope, XXXIX (March, 1970), 144-147.

Hall, Alice J. "Apollo 14: The Climb Up Cone Crater," National Geographic, CXL (July, 1971), 136-148.

Mason, Brian. "The Lunar Rocks," Scientific American, CCXXV (October, 1971), 48-58.

O'Keefe, John A. "Tektites and Impact Fragments From the Moon," Scientific American, CCX (February, 1964), 50-57.

Shoemaker, Eugene M. "The Geology of the Moon," Scientific American, CCXI (December, 1964), 38-47.

Weaver, Kenneth F. "And Now to Touch the Moon's Forbidding Face," National Geographic, CXXXV (May, 1969), 633-635.

Weaver, Kenneth F., et al. "The Incredible Story of Apollo 11," National Geographic, CXXXVI (December, 1969), 735-797.

UNIT XVI:

Chapman, Clark R. "The Discovery of Jupiter's Red Spot," Sky and Telescope, XXXV (May, 1968), 276-278.

Hide, Raymond. "Jupiter's Great Red Spot," Scientific American, CCXVIII (February, 1968), 74-82.

Kuiper, Gerald P. "Lunar and Planetary Laboratory Studies of Jupiter," Sky and Telescope, XLIII (January, 1972), 4-8.

Murray, Bruce C. "Mars From Mariner IX," Scientific American, CCXXVIII (January, 1973), 48-69.

"Pioneer 10 Mission to Jupiter," Sky and Telescope, XLIII (May, 1972), 299-302.

"Soviet Exploration of Mars," Sky and Telescope, XLIII (February, 1972), 91-93.

"Three Spacecraft Study the Red Planet," Sky and Telescope, XLIII (January, 1972), 14-17.

UNIT XVII:

Eshleman, Von R. "The Atmospheres of Mars and Venus," Scientific American, CCXX (March, 1969), 78-88.

Newell, Reginald E. "The Circulation of the Upper Atmosphere," Scientific American, CCX (March, 1964), 62-74.

"New Radar Maps of Venus," Sky and Telescope, XL (November, 1970), 274-275.

"Water Vapor on Venus," Sky and Telescope, XXVII (June, 1964), 331, 348.

UNIT XVIII:

Frieden, Earl. "The Chemical Elements of Life," Scientific American, CCXXVII (July, 1972), 52-60.

Mirsky, Alfred E. "The Discovery of DNA," Scientific American, CCXVII (June, 1968), 78-88.

"The Outlook for Nuclear Spacecraft," Sky and Telescope, XXXVI (August, 1968), 88-90.

Turner, Barry E. "Interstellar Molecules," Scientific American, CCXXVIII (March, 1973), 50-69.

In addition to the above references, interesting articles on the sun are listed as follows:

Friedman, Herbert. "Our Life-Giving Star, the Sun," National Geographic, CXXVIII (November, 1965), 713-743.

Menzel, Donald H., and Jay M. Pasachoff, "Solar Eclipse, Nature's Super Spectacular," National Geographic, CXXXVIII (August, 1970), 222-223.

Parker, E. N. "The Solar Wind," Scientific American, CCX (April, 1964), 66-76.

Sprague, Gale C. "Visual Studies of the Aurora," Sky and Telescope, XXXV (June, 1968), 346-349.

Starr, Victor P., and Peter A. Gilman. "The Circulation of the Sun's Atmosphere," Scientific American, CCXVIII (January, 1968), 100-113.

PART II:

The following film list is taken from the catalogues of educational films of six large universities. The list is arranged as was the written reference material, i.e. with respect to the applicable unit(s). The educational film centers surveyed are:

Audio-Visual Center
Indiana University

Bureau of Audio-Visual Instruction
University of Wisconsin

Film Center of Syracuse University

Instructional Media Center
Michigan State University (Catalog lists University of Michigan films also.)

Visual Aids Service. Division of University Extension
University of Illinois

Included with each film is a short description of the contents and the duration. Films listed as part of the supplementary information are not repeated.

UNITS I AND II:

"Eclipses of the Sun and Moon." 11 minutes (Nature of solar and lunar eclipses), Syracuse.

"Galileo," 11 minutes (Events of Galileo's struggle for the right of science to question tradition), Indiana.

"How Vast Is Space?" 18 minutes (Imaginary journey to the edge of infinity and then back to the nucleus of the atom), Michigan State.

"Powers of Ten," 10 minutes (A trip beyond the galaxies and then back into the atom, each step in film increasing or decreasing by a power of ten), Michigan.

"Sun Watchers," 30 minutes (Review of man's changing concepts of the sun from Ptolemy, Copernicus, to present, with emphasis on techniques of solar observation by scientists of today), Illinois.

"What Is Space?" 11 minutes (Concept of space; complex movements in space; use of light years to measure distances), Michigan State.

UNITS III AND IV:

"Astronomer," 16 minutes (Work, methods, and tools of astronomy; Hale telescope along with many other types of instruments), Michigan State.

"Charting the Universe With Optical and Radio Telescopes," 13 minutes (Work of astrophysicists and radio astronomers who analyze outer space light and signals), Michigan State.

"Dark Lines to the Planets," 19 minutes (Explains how absorption spectroscopy is used to determine atmosphere of planets), Illinois.

"Fingerprints of the Stars," 29 minutes (Discusses various instruments and methods used in gaining knowledge of stellar composition and in studying objects in space), Indiana.

"How We Study the Sun," 15 minutes (How study of the sun's light shows various kinds of activity on the sun and the elements present on it), Illinois.

"Measuring the Universe," 11 minutes (Shows how astronomers measure vast distances between galaxies), Syracuse.

"Mystery of Stonehenge I and II," 57 minutes (Account of prehistoric stone monument in England; the theory that it was built as an observatory and as a computer; reactions of scientists and authorities to theory and to its confirmation in 1964), Illinois.

"Space Science: Studying the Stars," 14 minutes (How astronomers gather information about stars; methods used to determine distance, brightness, magnitude, heat, composition, movement, size), Illinois.

"Story of Palomar," 22 minutes (Development of the Hale telescope and theory of reflectors), Illinois.

UNIT VII:

"Energy From the Sun," 16 minutes (Sun's role in supplying earth's energy; hydrogen fusion as a source of electromagnetic radiation), Syracuse.

"Force of Gravity," 27 minutes (How gravity brings order to the universe and earth; history from Copernicus through Einstein), Michigan State.

UNITS VIII, IX, AND X:

"Beyond Our Solar System," 11 minutes (Basic concepts about stars, nebulae, major constellations, and galaxies), Michigan State.

"Exploring the Milky Way," 29 minutes (Use of Mira variable stars in deducing and reconstructing probable origin and evolutionary history), Michigan State.

"Galaxies and the Universe," 29 minutes (Explores modern astronomy's present conception of the universe; reviews physical properties of Milky Way and considers other possible solar systems), Indiana.

"Milky Way," 11 minutes (Physical properties of the Milky Way along with telescopic photographs), Michigan State.

"Motion and Time," 11 minutes (Theory of relativity, philosophical and experimental developments leading to present definitions of time and motion), Michigan State.

"Nebulae and Clusters," 29 minutes (Discusses star groupings, double and multiple stars, and galactic and globular clusters; theory of star formation), Indiana.

UNIT XII:

"Exploring the Universe," 11 minutes (Dynamic aspects of stars within our galaxy and of the galaxies themselves; the motion of stars and a portrayal of the theory of the expanding universe), Michigan State.

"Universe," 28 minutes (Journey through space beyond the solar system into far regions of sky now perceived by astronomers), Michigan State.

UNIT XIII:

"Calendar: Story of Its Development," 11 minutes (Traces development of our calendar through Egyptian, Babylonian, and Roman cultures and down to the Julian and Gregorian calendar which we use today), Syracuse.

"Interplanetary Space," 23 minutes (Portrait of sun's family including planets, meteors, asteroids, comets; discusses solar wind and effects), Illinois.

"Solar Family," 11 minutes (Animated solar system according to plantesėmal hypothesis; motions of planets; Halley's comet), Wisconsin.

"Space Science: Comets, Meteors, Planetoids," 11 minutes (Theories of origin; spectroscope, radio, and optical telescopes; meteor shower of 1833; Halley's comet), Michigan State.

"The Wanderers: The Paths of Planets," 10 minutes (Our knowledge traced from its earliest notions, through Kepler's laws, to our present ideas), Syracuse.

UNIT XIV:

"Continental Drift," 10 minutes (Presents in animation the idea that our continents were formed from part of one super-continent), Michigan State.

"Earth: Its Structure," 11 minutes (Animated drawings present the most widely accepted theory of the formation of our earth and solar system), Syracuse.

"Hidden Earth," 27 minutes (Earth physics; research techniques in seismology; modern understanding of earthquake waves and what they tell about the crust, mantle, and core of the earth; earth's structure), Michigan.

"Shape of the Earth," 27 minutes (Research into dimensions and motions of planet; wobble of earth around its axis; unreliability of plumb line measurements), Syracuse.

UNIT XV:

"Moon," 11 minutes (Lunar phenomena; concept of tides; phases of moon; orbit; lunar month; sunrise and sunset on the moon; lunar path in space), Michigan State.

"Origin of the Moon," 5 minutes (Shows theory of whirling gasses that condensed and formed earth and moon), Syracuse.

UNIT XVIII:

"Life on Other Planets," 24 minutes (Reviews facts and principles of biology in answering key questions; how life might be expected to arise), Syracuse.

PART III:

Listed in the Astronomy Education Newsletter of December, 1972, were six sources of Kellerized course materials. They are all for undergraduate non-science majors. Copies of these materials are available upon written request.

Course	Contact
"Introduction to Astronomy" ($2.50 per set, checks payable to Rice University)	Dr. A. J. Dessler Space Science Department Rice University Houston, Texas 77001
"Astronomy: What's Up There; How Has It Affected Us?" ($2.50 per set, checks payable to American University)	Dr. H. W. Leidecker Department of Physics American University Washington, D.C. 20016

"Astronomy of the Solar System"	Dr. Frank Six Dept. of Physics and Astronomy Western Kentucky University Bowling Green, Kentucky 42101
"Methods in Astronomy"	Dr. William H. Jefferys Department of Astronomy The University of Texas at Austin Austin, Texas 78712
"Elementary Astronomy"	Dr. Leon Schroeder Physics Department Oklahoma State University Stillwater, Oklahoma 74074
"Natural Sciences 9"	Mr. Michael Zeilik, II Harvard College Observatory Cambridge, Massachusetts 02138

BIBLIOGRAPHY

BIBLIOGRAPHY

Abell, George O. "And Now, May I Wish You All a Very Good Morning." The Planetarian, I (September 21, 1972), 35-40.

________. Exploration of the Universe. Brief Edition. New York: Holt, Rinehart and Winston, 1969.

________. Exploration of the Universe. 2nd ed. New York: Holt, Rinehart and Winston, 1969.

"Abrams Planetarium Annual Report, 1972-73." Submitted to Associate Director, Continuing Education Services, Michigan State University.

Africk, Steven A. "Where Is Astronomy Education Headed?" Sky and Telescope, XLII (November, 1971), 277-278.

Asimov, Isaac. The Universe. New York: Avon, 1966.

Berendzen, Richard Earl. "On the Career Development and Education of Astronomers in the United States." Unpublished Ph.D. dissertation, Harvard University, 1968.

Bergamini, David, and the Editors of Time-Life Books. The Universe. New York: Time-Life Books, 1971.

Birney, D. Scott. Modern Astronomy. Boston: Allyn and Bacon, 1969.

Bliss, Robert C. "The Elementary Astronomy Course for Non-Science Majors." Projector, III (April, 1970), 11-13.

Bok, Bart J. "The Spiral Structure of Our Galaxy--I." Sky and Telescope, XXXVIII (December, 1969), 392-395.

________. "The Spiral Structure of Our Galaxy--II." Sky and Telescope, XXXIX (January, 1970), 21-25.

Burbridge, Geoffrey, and Hoyle, Fred. "The Problem of the Quasi-Stellar Objects." Scientific American, CCXV (December, 1966), 40-52.

Burbridge, Margaret, and Lynds, C. Roger. "The Absorption Lines of Quasi-Stellar Objects." Scientific American, CCXXIII (December, 1970), 22-29.

Canby, Thomas Y., and Blair, James P. "California's San Andreas Fault." National Geographic, CXLIII (January, 1973), 38-53).

Connes, Pierre. "How Light Is Analyzed." Scientific American, CCXIX (September, 1968), 72-82.

Cook, David W. "How We Mapped the Moon." National Geographic, CXXXV (February, 1969), 240-246.

Dessler, A. J. Proceedings, Keller Method Workshop Conference. Houston, Texas, March 18, 1972.

Educational Films, 1969. East Lansing: Instructional Media Center, Michigan State University, 1969.

Educational Films, 1972-75. Visual Aid Service, Division of University Extension, University of Illinois, 1972.

Educational Motion Pictures--1968. University Extension, The University of Wisconsin, 1968.

Emlen, Stephen T. "The Celestial Guidance System of a Migratory Bird." Sky and Telescope, XXXVIII (July, 1969), 4-6.

"The Exploration of Venus." Sky and Telescope, XLI (February, 1971), 81-83.

Friedman, Herbert. "Our Life-Giving Star--The Sun." National Geographic, CXXVIII (November, 1965), 713-743.

Gingerich, Owen J. "Johannes Kepler and Rudolphine Tables." Sky and Telescope, XLII (December, 1971), 328-333.

Goldreich, Peter. "Tides and the Earth-Moon System." Scientific American, CCXXVI (April, 1972), 42-52.

Green, Louis C. "Observational Aspects of Cosmology." Sky and Telescope, XXXI (April, 1966), 199-202.

________. "Quasars, Six Years Later." Sky and Telescope, XXXVII (May, 1969), 290-294.

Hack, Margherita. "The Hertzsprung-Russell Diagram Today--I." Sky and Telescope, XXXI (May, 1966), 260-263.

________. "The Hertzsprung-Russell Diagram Today--II." Sky and Telescope, XXXI (June, 1966), 333-336.

Hall, A. Rupert, and Smith, Norman A. F. "Invention." Encyclopedia Americana. International Edition. (1973).

Hardie, R. H., and Krebs, M. E. "Finding Sidereal Time." Sky and Telescope, XLI (May, 1971), 288-289.

Hynek, J. Allen, and Apfel, Necia H. Astronomy One. Menlo Park, California: Benjamin, 1972.

Kals, William S. "Polynesian Navigation." Sky and Telescope, XXXIII (June, 1967), 358-360.

Keller, Fred S. "Goodbye Teacher." Journal of Applied Behavioral Sciences, I (1968), 79-89.

Lawless, James G., and Folsome, Clair E. "Organic Matter in Meteorites." Scientific American, CCXXVI (June, 1972), 38-46.

Mager, Robert F. Preparing Instructional Objectives. Palo Alto: Flaron, 1962.

Margenau, Henry; Bergamini, David; and the Editors of Time-Life Books. The Scientist. New York: Time-Life Books, 1971.

Mathews, Samuel W. "The Changing Earth." National Geographic, CXLIII (January, 1973), 1-37.

McMillan, Robert S., and Kirszenberg, John D. "A Modern Version of the Ole Roemer Experiment." Sky and Telescope, XLIV (November, 1972), 300-301.

Menzel, Donald H.; Whipple, Fred L; and de Vaucouleurs, Gerald. Survey of the Universe. Englewood Cliffs, New Jersey: Prentice-Hall, 1970.

Motz, Lloyd, and Duveen, Anneta. Essentials of Astronomy. New York: Columbia, 1971.

Mullaney, James, and McCall, Wallace. The Finest Deep Sky Objects. Cambridge, Massachusetts: Sky Publishing Corporation, 1966.

1970 Catalog--Educational Motion Pictures. Audio-Visual Center, Indiana University, 1970.

Page, Thornton L. "The Evolution of Galaxies--I." Sky and Telescope, XXIX (January, 1965), 4-10.

Payne-Gaposchkin, Cecilia, and Haramundanis, Katherine. Introduction to Astronomy. Englewood Cliffs, New Jersey: Prentice-Hall, 1970.

Rosemergy, John Charles. "An Experimental Study of the Effectiveness of a Planetarium in Teaching Selected Astronomical Phenomena to Sixth Grade Children." Unpublished Ph.D. dissertation, University of Michigan, 1967.

Sagan, Carl; Leonard, Jonathan Norton; and the Editors of Time-Life Books. Planets. New York: Time-Life Books, 1972.

Schmidt, Martin, and Bello, Francis. "The Evolution of Quasars." Scientific American, CCXXIV (May, 1971), 54-69.

Smith, Billy Arthur. "An Experimental Comparison of Two Techniques (Planetarium Lecture-Demonstration and Classroom Lecture-Demonstration) of Teaching Selected Astronomical Concepts to Sixth Grade Students." Unpublished Ed.D. dissertation, Arizona State University, 1966.

Stent, Gunther S. "Prematurity and Uniqueness in Scientific Discovery." Scientific American, CCXXVII (December, 1972), 84-93.

Strobe, Marvin Barnard. "A Comparison of Factual and Conceptual Teaching in Introductory College Astronomy." Unpublished Ed.D. dissertation, Utah State University, 1966.

Syracuse Films--1972. Film Center of Syracuse University.

"The 'Keller Method' of Teaching and Examples in Astronomy." Astronomy Education Newsletter (December, 1972), 10-11.

Wallbank, T. Walker. "World History," World Book Encyclopedia (1972), Vol. XXI.

Weaver, Kenneth F. "Journey to Mars." National Geographic, CXLIII (February, 1973), 231-263.

Wilson, Curtis. "How Did Kepler Discover His First Two Laws?" Scientific American, CCXXVI (March, 1972), 92-106.

Wyatt, Stanley P., Jr. "Astronomy in the Colleges." Sky and Telescope, XIV (July, 1955), 375.

________. "College Programs for Astronomy Majors." Sky and Telescope, XIV (September, 1955), 459.