THE CHANGING SEASONS: TEACHING FOR UNDERSTANDING

Abstract

Seasons are part of most school science curricula yet many children and adults have a limited understanding of underlying causes of seasonal changes. This paper reviews approaches used in teaching seasons to primary and lower secondary school pupils over the past two hundred years. From the early 1800s, the same diagrams have been used to teach about the seasons despite changes in the background knowledge of students and teachers, and changes in theories of teaching and learning. Accompanying text has changed over time--what once may have taken several pages to explain is now often explained on one page with one diagram. It is suggested that some older explanations and approaches to teaching about the seasons provide insight for contemporary teachers seeking to assist students to reach improved understanding of the seasons.

Introduction

Whenever a science curriculum is designed for students in primary or lower secondary schools, the topic "seasons" is almost certain to be included, and this has been the case for at least the past two hundred years. However, there is convincing evidence that this topic is not well understood by many students and teachers (Atwood & Atwood, 1996; Furuness & Cohen, 1989; Sadler, 1998; Schoon, 1988; Schneps, 1988). The purpose of this paper is to review approaches to teaching primary and lower secondary school students about the seasons with a view to suggesting improved curricular and pedagogical practice that might result in greater understanding of the seasons. In general, we employ the usual meaning of "seasons" based on four roughly equal periods of the year marked by the passage of equinoxes and solstices, although we recognise that in Australia there are numerous different meanings related to cultural and geographical factors that are of significance.

It has been known for centuries that the sun appears higher in the sky in summer than in winter, resulting in differing intensities of solar radiation incident on any given horizontal area of Earth's surface. This is the key to understanding the cyclical seasonal changes experienced on Earth. It is irrelevant whether one assumes a geocentric or heliocentric frame of reference--one can understand the occurrence of the seasons equally well in either case. We suggest that a geocentric frame of reference, which supports direct observations and experiences of phenomena associated with the passing of the seasons, is the more appropriate for younger students and provides an essential foundation for further learning.

The seasons in the school curriculum and textbooks

In the mid nineteenth century, an American edition of a Scottish text Introduction to the Sciences: Presenting a systematic view of nature (Reese, 1855) designed for schools and academies set out "to survey the wonderful works of God systematically" (p. 9). One of the earliest topics included in this book is an explanation of the seasons. After establishing that Earth is a rotating globe of diameter 7902 miles, and defining the terms "equator", "Pole", "Meridian lines", "Tropic of Capricorn" and "Tropic of Cancer" it proceeds as follows:

These lines, artificial as they are refer to natural circumstances. The earth does not move with its pole quite upright or perpendicular, but in an inclined or stooping posture, the departure from the perpendicular being as much as 23 1/2 degrees of the 90 degrees constituting the quarter of the circle. This oblique arrangement produces those beneficial and agreeable variations of heat and light, which we term the Seasons. In the next engraving the sun is represented as nearly in the centre of the oval orbit of the earth.

The earth is seen at four different points in its annual course. At B and D, where it is on the 21st of March and 21st of September, the heat and light of the sun hit it at the equator. When the earth is at A, the upper or north pole is in darkness, and the sun is not there seen for several weeks. When it is at C, the south part of the globe is in the same state. And when one pole is thus darkened, the opposite one has constant daylight for the same length of time. (Reese, 1855, pp. 21-22)

In similar fashion it discusses mid summer in different hemispheres, tropical and more temperate climates. Stripped of its dated language, this heliocentric explanation of the seasons and the accompanying diagram have much in common with treatments of the same topic to be found in contemporary school curriculum documents and texts, although few contemporary curriculum developers would justify the inclusion of science in quite the same fashion as did Reese.

Edward Jackson was an instructor in physical science in the Boston Latin School when his text book The Earth in Space - A Manual of Astronomical Geography (Jackson, 1894) was published. Jackson's treatment of the seasons varied from earlier texts. The sequence for the introduction of concepts relevant to the seasons was: dimensions and distances (including diameter of Earth and parallax); the sun's rays and Earth's atmosphere; gradual changes in light and heat during the day and year (including a diagram describing the diurnal variation in angle of solar radiation but clearly important for discussions of seasonal variation) (See Figure 1); Earth's daily motion (including day and night, and diurnal motion of "heavenly bodies"); and Earth's yearly motion.

Discussion of the seasons follows, with the explanation that the sun's annual apparent motion "is in consequence of the earth's two motions going on together" (pp. 54-55). The effects of this annual motion include the change of seasons and the variation in the length of day and night. The familiar diagram showing locations of Earth in its orbit at different seasons appears early in the discussion, but in relation to the supposition that Earth's axis be perpendicular to the plane of the ecliptic.

94. Suppose the Earth's Axis were Perpendicular to the Plane of the Ecliptic (Fig. 25), then the plane of the ecliptic would coincide with the equator, and the sun would, accordingly, always be seen over the equator. His northernmost rays would always strike exactly at the north pole; his southernmost rays, at the south pole.

Those rays which reach us would come in precisely the same direction every day throughout the year, and there would be nothing to produce a change of seasons except the difference in our distance from the sun at different points of the orbit ... This difference, however, is so extremely slight that in all probability ordinary observers could not detect the consequent difference in temperature,[*] and consequently there would be perpetual winter in the frigid zones, perpetual spring in the temperate zones, and perpetual summer at the equator.

(* Whatever difference there might be would be just opposite to that produced by the sun's declinations, at least in the northern hemisphere, for we are nearest the sun in winter. Original footnote) (pp. 57-58)

Jackson considers the seasonal variation in the length of day and night by reference to a series of diagrams such as those shown as Fig. 27 and Fig. 28 (See Figure 2) rather than by reference to a diagram similar to his Fig. 25 above with Earth's axis tilted.

This approach loses the constancy of the orientation of Earth's axis in space, but the diagrams complement the associated text better than the traditional single diagram. This book is the earliest school text we have found that identifies and explains the seasonal phenomenon that:

although the hottest rays fall at the summer solstice, yet our warmest weather does not come until some time afterwards. We continue to receive more heat during the days following than we lose during the nights. Thus the great heat of a July or August day [Northern hemisphere] is not produced entirely by the sun of that day, but is an accumulation of the heat of the several preceding weeks. For a like reason we do not experience the greatest cold at the winter solstice. (p. 64)

Jackson adopted both geocentric and heliocentric frames of reference. His extensive treatment was somewhat atypical of school text books at that time, most of which contained succinct text in question and answer format, with little if any discussion of seasonal phenomena, or of students' personal experiences of such phenomena.

Midway through the twentieth century in Australia, science curriculum documents were emphasising the need to provide for students opportunities "to discover relationships for themselves, to develop their own explanations and to apply what they have learnt to new situations" (Department of Education, Queensland, 1967, p. 1). Syllabus topics were stated briefly, and notes for the guidance of teachers were provided. A grade 8 topic was "Introduction to the sun--observation of time and direction of rise and set of sun, length of day and night, solstices and equinox" (p. 3). Earlier topics included observations of the night sky, apparent rotation of the heavens, and annual movement of some well known constellations. In relation to the topic "introduction to the sun" the notes read, in part:

The earth rotates around the sun--the earth's axis is inclined when compared to the orbit it travels around the sun. Because the axis is inclined, during rotation around the sun--

(i) the length of day and night varies through the year.

(ii) climate varies through the year for any one part of earth.

Experiment:

A globe-torch experiment can be devised to demonstrate these facts.

Project:

Students should keep a personal record of the direction in which the sun rises and sets, and record the information as follows:--

Make twelve circles to represent each month of the year and make a dot at [the] centre to represent a vertical post. Mark in the four compass points. About the twenty-second day of each month, find the direction in which the sun rises and sets. Also measure length of the shadow made by the post at midday on this day.

On which day was shadow shortest? Longest? On which day did sun rise due east and set due west?

On which day did sun rise and set furthest south? north?

Use the information in a newspaper to determine the length of day and night on each of these days.

On which day was length of day and night equal?

On which day was length of day greatest?

On which day was length of day shortest?

Use the experimental results to define and explain the solstices and equinox. (Department of Education Queensland, 1967, pp. 5-6)

It is apparent that students in Queensland were expected to operate, at least initially, from a geocentric frame of reference in making and interpreting their astronomical observations. In similar fashion, the popular Australian text, Science for High School Students (Nuclear Research Foundation, 1964), which was written in response to a major curriculum reform in New South Wales, adopted a geocentric frame of reference to introduce astronomy topics. For example, it devotes a substantial amount of space to apparent stellar motion, curved paths perceived differently from different locations, shadows, direction of the sun seen from different latitudes, and seasonal variations in the sun's apparent motion before deducing the tilt of Earth's axis from the angle between the ecliptic and the plane of the celestial equator.

By way of contrast, the cause of the seasons was still described in many school science texts by reference to a heliocentric frame of reference. One such text, first published in Australia in 1966 with a second edition in 1979 is In Search of Science (Russell, Cusack, & Mayfield, 1979). The "tilt" of Earth's axis is first shown in a diagram. Five short paragraphs, supported by several additional diagrams, precede a summarising statement in colour: "When our hemisphere is inclined towards the Sun we have Summer. When it is tilted away we have Winter" (p. 28)

Primary Investigations (Australian Academy of Science (AAS), 1994), an adaptation of the BSCS program Science for Life and Living, introduces the question "How can we find out what causes winter and summer?" in Book 6 of seven designed for use throughout the primary school. Using a series of simple diagrams depicting an inflated balloon to represent Earth and a torch to represent the sun, students are directed "to tilt the balloon slightly, so that the North Pole faces towards the sun" as a representation of the southern winter. Subsequent diagrams depict the balloon in three other locations representing the other three seasons, although no attempt is made to depict, or to discuss in the accompanying text the orbit of Earth around the sun. The initial diagram in the series shows the North Pole at the bottom, unusual but perhaps appropriate for the intended Southern Hemisphere readers. However, this may have been a drafting error, as the remaining diagrams reinstate the North Pole to its more conventional position at the top of the diagram. Perhaps surprisingly, this treatment of the causes of the seasons for upper primary school students involves just one group activity which involves the conceptions of a spherical Earth, tilted axis, and constant orientation of axis as Earth completes its orbit around the sun. It includes no reference, implicit or explicit, to students' prior knowledge or experience of relevant phenomena in presenting a model of the scientifically accepted explanation of the seasons.

The inclusion of the causes of the seasons in the majority of textbooks for elementary school students published by leading publishers in the United States of America (Atwood & Atwood, 1996) confirms our personal experience over many years that teachers commonly include this topic in the science program in the early and middle grades. It is frequently revisited, in substantially the same detail, in junior secondary school. In most cases, a heliocentric frame of reference is adopted, in the form of the tilted axis diagram, and little attention is given to students' lived experiences of daily and annual movements of the sun and related environmental changes. The tilted axis explanation for the seasons is supported by a small amount of explanatory text, few if any complementary activities, and no discussion of students' personal related experiences of phenomena such as changing amounts of daylight, changing shadows, or seasonal variations in temperature or local vegetation. Some of the earliest textbooks that we have studied included substantial discussion of such phenomena, frequently in advance of, and as justification for posing, the question about the causes of the seasons (Ferguson, 1756; Jackson, 1894; Leonard, 1837; Niver, 1916; Parley, 1831; Smith, 1875). In our view, the approach to teaching about the seasons taken in some of these old text books is more consistent with contemporary theories of learning than that adopted in many current text books.

What constitutes a satisfactory set of conceptions about the seasons?

All of the elements of a contemporary explanation of the seasons have been known for centuries but, as stated earlier, many contemporary students and some teachers are unable to provide a scientifically acceptable explanation. This is not to suggest that they do not have a set of conceptions about the seasons, some experientially based and others explanatory. Examples of experientially based conceptions about the seasons include the changing length of daylight, higher summer temperatures, temporary absence of certain produce from the supermarket shelves, and appropriate times to engage in outdoor activities such as swimming or football.

Examples of explanatory conceptions about the seasons include Earth is closer to the sun during summer, Earth tilts towards the sun during summer and away from the sun during winter, and the sun gets hotter during the summer (Furuness & Cohen, 1989). These three common explanatory conceptions are not scientifically acceptable although the first two seem likely to have resulted from some form of instruction. Similarly, students commonly have conceptions about seasonal conditions at specific locations on Earth which are erroneous. For example, the idea that all places on Earth have 12 hours of daylight and 12 hours of night at each equinox is not accurate in relation to polar regions, and the common belief that the sun never rises south of East at locations south of the Tropic of Capricorn is false.

What then constitutes a satisfactory set of conceptions about the seasons? One approach to determining what might constitute a satisfactory set of conceptions about the seasons is to consult a range of text books. Table 1 presents the results of such consultation in relation to 10 texts published between 1756 and 1994. It is clear that the spherical shape of Earth, the tilt of its axis, and the eccentricity of its orbit, have featured prominently, together with the constancy of orientation of Earth's axis, variation in length of daylight and night, and the different intensity of solar radiation on Earth's surface. Of these only one, the variation in length of daylight and night, is directly observable. It may be that the authors of the texts that omit reference to directly observable phenomena such as the sun's elevation, locations of the sun's rising and setting, and length of day and night assume that these lie within the students' experience, however they do not make reference to them.

A different approach to determining a satisfactory set of conceptions about the seasons recognises the incremental nature of learning and assumes that what constitutes "a satisfactory set of conceptions" is dependent on the age and prior learning experiences of the individuals concerned. Common to a satisfactory set of conceptions about the seasons for all ages would be those phenomena that are either directly observable or easily available to children through activities with shadows, calendars and print and electronic media. These include: seasonal changes in length of daylight and night; variations in the sun's elevation and locations of the sun's rising and setting; different intensity of the sun's radiation on Earth's surface; and differences in the timing, nature and contrast between seasons in various locations. From such an experiential base, of necessity geocentric in character, emerge questions whose answers involve the sphericity of Earth and its orientation and movement in space, likely to be addressed appropriately by secondary school students and adult learners.

An obvious question is "What do teachers need to know about the topic Seasons in order to teach it well to students of various ages?" Two of the texts listed in Table 1 were written for primary (elementary) school teachers (Blough & Schwartz, 1974; Victor, 1965). They include extensive discussions of curriculum issues and theories of teaching and learning that were current, comprehensive accounts of science concepts commonly included in school science curricula, and practical suggestions for how to teach them to children of various ages. Implicit in this approach is recognition by the authors that teachers need to have a sophisticated understanding of both the science concepts and how children learn them. Victor (1965,p. 5), in referring to the demise of Nature Study in elementary schools in the United States, observed "nature study was introduced by people who were both specialists in science and master teachers. They were able to make the study of nature a dynamic and unforgettable learning experience for children." In our view, the combination of a broad understanding of the discipline and of teaching and learning is as crucial now as it ever has been (Cohen & Lucas, 1999).

Implications for teaching

The past fifty years has brought many changes in science curriculum and pedagogy. One of the most significant has been the gradual inclusion in primary and lower secondary science courses of the subject matter and processes of science formerly found in upper secondary and tertiary courses. In response to this trend, Symington (1982) urged that the selection of both content and teaching strategies employed in primary schools should be dictated by what is appropriate to the children. In particular, he argued

> that in primary school science we should not be concerned with invoking and using the models which scientists devise to explain observations. Rather our concern should be that pupils' experiences be used to help them build appropriate concepts. (p. 34)

Symington's advice is consistent with contemporary constructivist theories of learning. In relation to teaching about the seasons, it implies that modelling Earth in orbit around the sun while maintaining a constantly inclined axis is an inappropriate place to start with young students. It may even be an inappropriate instructional target at which to aim.

Recently we were reminded of the importance of acknowledging everyday experiences and understandings held by students in planning instruction. One of us (MC) attended a concert at which Vivaldi's The Four Seasons was performed. Children from two local primary schools had been invited to enter a competition by submitting a painting depicting the seasons. The entries were on display, and a large proportion of students had divided their painting into four equal parts, one for each season. What we found surprising was that many students had depicted winter involving deep snow, trees devoid of leaves and at least one snowman (See three examples of the children's paintings on the front cover of this issue).

When we visited one of the schools and talked to the children about their paintings, we discovered that very few had ever encountered a winter like that depicted in their paintings. Furthermore, many had difficulty describing for us differences between summer and winter in Brisbane, the place where they had spent almost all of their 10 or 11 years. The students' understanding of seasonal phenomena appeared to be based on vicarious experiences of seasons in other countries and devoid of first hand knowledge of seasonal changes evident in their local environment. It transpired that they had studied the seasons in class, and some provided explanations which included many of the misunderstandings with which we have become familiar. Not one student had attempted to depict in his or her painting any element of the scientific model of the cause of the seasons or the observations on which it is based.

Teachers need to decide what is, and what is not appropriate for specific students despite what curriculum, texts and teachers' conventional training dictate. In addition to historical text books in astronomy, there is a substantial body of research to which teachers can turn. For example, alternative conception research documents probable alternative conceptions that children will bring to class, or develop as a result of instruction (Atwood & Atwood, 1996; Furuness & Cohen, 1989; Sadler, 1998; Schoon, 1988). In relation to the seasons, the most common such idea is that Earth is closer to the sun during the summer months--true only for the southern hemisphere but irrelevant as a cause of the seasons everywhere. Such knowledge has the potential to assist teachers to enhance their teaching by anticipating what their students are likely to "know" about the topic and, in line with Ausubel's (1968) oft repeated dictum, teaching them accordingly.

We suggest that knowledge based on direct observation constitutes an essential foundation for students to understand the scientifically accepted explanation of the seasons. The only concepts listed in Table 1 which are subject to direct observation are variation in the length of daylight and night, variation in solar elevation throughout the year, and variation in the locations at which the sun rises and sets throughout the year. These concepts, together with the different intensity of solar radiation which result from changes in the sun's elevation, are very likely essential for subsequent understanding of the traditional explanation of the causes of the seasons.

By way of contrast, the only concepts related to the seasons included in all text books listed in Table 1 are the spherical shape of Earth and the tilt of Earth's axis. These, together with the constancy of orientation of Earth's axis and the irrelevant elliptical orbit of Earth around the sun, provide the basis for the traditional explanation of the seasons found in school curricula and text books. None of these is directly observable yet they are associated with many of the most common and persistent alternative conceptions, held by students from primary school through university and almost certainly the unintended products of instruction.

Teachers might well seek to understand and exploit students' prior understanding of their changing environment throughout the year in planning and conducting lessons about the seasons. Lucas and Broadfoot (1991) provided some general guidelines for an astronomy program for primary school students over the period of one year. Suggested activities were spread throughout the year, including some designed to provide a foundation for eventual understanding of the causes of the seasons, perhaps in a later grade in the primary school or in secondary school. These activities are summarised in Table 2. Other appropriate resources for teachers include: science teachers' journals; curriculum resource materials, some of which are available on the Internet; research reports documenting students' alternative conceptions about Earth and space concepts (Atwood & Atwood, 1996; Wandersee, Mintzes, & Novak, 1994); non-science books for children featuring seasonal changes; and children's conversations and spontaneous questions about their local environment.

We began by remarking on the ubiquitous nature of the topic "seasons" in science curricula for primary and lower secondary students over the past two hundred years. It is perhaps timely for teachers to question why students at the close of the twentieth century all need to understand the underlying causes of the seasons. Justifications for inclusion of this topic in terms of relevance to astrology, agriculture or religious observance are no longer tenable. One might argue that there is potential relevance for many in relation to design and maintenance of home and garden, solar energy, leisure activities, understanding of different cultures and the like. The question of relevance is important because the answer, no doubt different for students of differing ages and abilities, suggests to the teacher where to start, what to include and just as importantly, what to postpone until the students have appropriate prior knowledge and experiences upon which to build a more complete scientific understanding.

Acknowledgments

We would like to express our appreciation to Marylene Altirei, Special Collections Librarian/Archivist and Gladys I. Dratch, Collections Development Librarian at the Monroe C. Gutman Library at the Harvard University Graduate School of Education. Their knowledge of the special textbook collection, their many suggestions, and especially their enthusiasm and encouragement made this work easier.

Table 1. Conceptions about the seasons and their inclusion in selected text books

Legend for Chart:

A - Conceptions about the seasons
B - Ferguson (1756)
C - Parley (1831)
D - Reese (1855)
E - Olmsed (1866)
F - Jackson (1894)
G - Nuclear Research Foundation (1963)
H - Victor (1965)[*]
I - Blough & Schwartz (1974)[*]
J - Russel et al (1979)
K - AAS (1994)

A	B	C	D	E	F	G	H	I	J	K
Earth is spherical	*	*	*	*	*	*	*	*	*	*
Obliquity of the ecliptic (i.e., the tilt of Earth's axis)	*	*	*	*	*	*	*	*	*	*
Constancy of oreintation of Earth's axis	*	--	--	*	*	--	*	*	*	*
Eccentricity of Earth's orbit	*	--	*	*	*	*	*	*	*	--
Earth nearer the sun is northern winter	*	--	--	*	*	--	--	*	*	--
Seasons more pronounced at higher latitude	*	--	*	--	*	--	--	*	*	--
Variation in length of daylight and night	*	--	*	*	*	*	*	*	*	--
Sun appears higher in the sky in summer	*	*	--	--	*					

than a winter	*	*	*	--	--					
Different intensity of solar radiation on Earth's surface	*	*	*	--	*	--	*	*	*	--
Sun rises and sets at different locations seasonally	*	--	--	--	*	*	*	--	*	--
Delayed onset of seasons	*	--	--	--	*	--	--	--	--	--

* These texts were written for prospective and experienced primary (elementary) school teachers

Shaded rows represent key conceptions for a geogenctric understanding of the seasons based on easily observable phenomena

Table 2. Suggested astronomy activities relevant to understanding the seasons, designed to be undertaken by primary school students during one year

Legend for Chart:

A - Month
B - Activity
C - Outcomes

A	B	C
March	Shadows: tracking the shadow cast by a vertical stick over several hours	Cooperative group work; measurement skills-angles, length; determination of true North; determination of local latitude.
--	Movement of sun: recording of time and bearing of sun rising or setting at 2-3 day intervals for approximately 4 weeks	Awareness solar diurnal motion; techniques of data management and interpretation-extrapolation and prediction.
April	Shadows: Shadow sticks, clocks and sundials	Heightened awareness of solar diurnal motion; knowledge of time zones, local noon etc.
June	Tracking solar path for entire mid-winter day: winter solstice	Understanding of two factors--length of day and altitude at culmination-- in determining winter temperatures.
August	Movement of sun: prediction of equinox and subsequent solar motion	

Extension of knowledge and understanding of annual solar motion; knowledge of meaning and occurrence of equinox; hypothesis formulation and testing.

October	Earth to sun distance: estimation of relative distance to sun at intervals throughout the year Determination of time of year when sun is closest to and furthest from Earth; construction of scale diagram of Earth orbit; knowledge that distance from sun not prime cause of seasons.

PHOTO (BLACK & WHITE): Figure 1. Fig. 10 in Jackson (1894,p. 26) depicting dispersion of differently oriented rays from the sun on the curved surface of Earth

PHOTO (BLACK & WHITE): Fig. 25. Axis Perpendicular to Ecliptic.

PHOTO (BLACK & WHITE): Figure 2. Figs. 27 and 28 in Jackson (1894,pp. 60-61) depicting Earth in relation to rays from the sun at vernal equinox and (Northern Hemisphere) summer solstice respectively

References

Atwood, R. K., & Atwood, V. A. (1996). Preservice elementary teachers' conceptions of the causes of seasons. Journal of Research in Science Teaching, 33(5), 553-563.

Australian Academy of Science. (1994). Primary investigations. Teacher resource book 6. Canberra: Author.

Ausubel, D. P. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart & Winston.

Blough, G. O., & Schwartz, J. (1974). Elementary school science and how to teach it (Fifth Edition). New York: Holt, Rinehart and Winston.

Cohen, M. R., & Lucas, K. B. (1999,July). Lunar shapes and shadows: What are the sources of our instructional ideas ? Paper presented at the Conference of the Australian Science Teachers' Association, Adelaide.

Department of Education Queensland. (1967). Syllabus in Science (A and B). Grades 8, 9 and 10. Brisbane: Government Printer.

Ferguson, J. (1756). Astronomy explained upon Sir Isaac Newton's principles, and made easy to those who have not studied mathematics. London: Author.

Furuness, L. B., & Cohen, M. R. (1989,April). Children's conceptions of the seasons: A comparison of three interview techniques. Paper presented at the National Association for Research in Science Teaching meeting.

Jackson, E. P. (1894). The Earth in space. A manual of astronomical geography. Boston: D.C. Heath & Co.

Leonard, L. W. (Ed.). (1837). The literary and scientific class book, embracing the leading facts and principles of science. Boston: T. H. Carter & Co.

Lucas, K., & Broadfoot, J. (1991,September). Astronomical activities throughout the year for primary school students. Paper presented at the Annual Conference of the Science Teachers' Association of Queensland, Kelvin Grove, Queensland.

Niver, H. B. (1916). Elementary geography, Part 1. New York: Hinds, Noble & Eldredge.

Nuclear Research Foundation. (1964). Science for high school students. Sydney: Nuclear Research Foundation within the University of Sydney.

Olmsted, D. (1866). A compendium of astronomy; containing the elements of the science, familiarly explained and illustrated. New York: Collins & Brother.

Parley, P. (1831). Peter Parley's tales about the sun, moon, and stars. Boston: Gray & Bowden, and Carter & Hender.

Reese, D. Meredith (Ed.). (1855). Introduction to the sciences: Presenting a systematic view of nature. By Messrs. Chambers of Edingburgh. New York: A. S. Barnes and Company.

Russell, I. D., Cusack, J. C., & Mayfield, J. M. (1979). In search of science. Book 1 (2nd edition). Richmond, Vic: Heinemann Educational Australia Pty. Ltd.

Sadler, P.M. (1998). Psychometric models of student conceptions in science: Reconciling qualitative studies and distractor-driven assessment instruments. Journal of Research in Science Teaching, 35(3), 265-296.

Schneps, M. H. (Project Director). (1988). A private universe [Videotape]. Available from Pyramid Film and Video, 2801 Colorado avenue, Santa Monica, CA 90404.

Schoon, K. J. (1988). Alternative conceptions in earth and space sciences: A cross age study. Unpublished PhD dissertation, Loyola University.

Smith, A. (1875). Smith's illustrated astronomy, designed for the use of the public or common schools in the United States. Boston: Nichols & Hall.

Symington, D. (1982). Treatment of content in primary science courses. Australian Science Teachers' Journal, 28(1), 31-35.

Victor, E. (1965). Science for the elementary school. New York: Macmillan.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), Handbook of research on science teaching and learning (pp. 177-210). New York: Macmillan.

~~~~~~~~

By Keith B. Lucas, Queensland University of Technology, Kelvin Grove, Qld and Michael R. Cohen, Indiana University Purdue University Indianapolis, USA

Dr Keith Lucas is an Associate Professor in the Centre for Mathematics and Science Education at QUT, where he teaches courses in science curriculum and research methodology

Dr Michael Cohen is Professor of Science Education and Chair of Teacher Education at IUPUI. His teaching and research interests lie in the field of science curriculum and children's concepts of science.
~~~~~~~~