DOCUMENT RESUME

ED 306 076 SE 050 436

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TITLE Misconceptions in the Earth Sciences: A Cross-Age Study.
PUB DATE Mar 89
NOTE 25p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (62nd, San Francisco, CA, March 30-April 1, 1989).
PUB TYPE Speeches/Conference Papers (150) -- Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Age Differences; Cognitive Mapping; *Concept Formation; *Earth Science; Elementary Secondary Education; Higher Education; Instructional Improvement; Learning Processes; *Misconceptions; *Science Instruction; *Scientific Concepts; Secondary School Science; Teacher Effectiveness

ABSTRACT

Misconceptions interfere with the formation of new insights and provide a faulty foundation. This causes difficulty in the learning of new materials. Therefore, effective teachers strive to know which misconceptions students have, and then develop a plan by which these suspected misconceptions can be corrected or averted. This paper reports on an investigation which was designed to determine the misconceptions in the earth and space sciences that appear to be prevalent, and to discover if certain individual characteristics are related to the misconceptions held. A questionnaire of 18 multiple choice items was administered to 1,213 students (5th, 8th, and 11th graders, and adults in college and trade school). Results indicated that the participants held many misconceptions in the earth sciences. Some subgroups appeared to have more misconceptions than others. Common misconceptions revealed by this survey were grouped into three types: (1) primary, which were misconceptions chosen more often than the scientifically acceptable conception; (2) secondary, in which the scientifically acceptable response was more frequently chosen, yet a particular distracter was still chosen twice as often as the least chosen distracter; and (3) functional, which was the least chosen response for that question. Six primary, 14 secondary, and 1 functional misconceptions were identified. Significant differences were found across genders, races, educational levels, and locations. (RT)

MISCONCEPTIONS IN THE EARTH SCIENCES:

A CROSS-AGE STUDY

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A paper presented at the 62nd annual meeting of the

National Association for Research in Science Teaching

San Francisco, California

March 30, 1989

INTRODUCTION

Perspectives on Misconceptions

Misconceptions interfere with the educational process. Nussbaum and Novick (1982) summarized the numerous studies concerning the effects of misconceptions, by stating that they may play a crucial role in learning by interfering with science comprehension. Children with misconceptions have a great deal of difficulty learning new materials because their misconceptions provide a faulty foundation for the formation of new insights. Therefore, teachers who want to teach effectively should know which misconceptions their students are likely to have, and then develop a plan so that these suspected misconceptions ca be averted or overcome.

Fisher (in Helm & Novak, 1983) defined misconceptions as ideas that are at variance with accepted views. Although the term misconception is in common usage among educators today, the word is disliked by some because of its connotation as being a wrong idea. Some scholars have proposed neutral terms such as alternative frameworks (Driver and Easley, 1978) and alternative conceptions (M. G. Hewson and P. W. Hewson, 1983). Fisher and Lipson (1986) noted that the term, misconception, is usually preferred by those whose job it is to teach, while the neutral terms are often preferred by those who see student behavior purely from the research viewpoint.

It is recognized that while misconceptions have been shown to interfere with learning, and even though they can be erroneous understandings, they are not necessarily the result of a lack of reasoning ability. Ault (1984b) has shown that misconceptions of children are often the result of imaginative and very perceptive thinking.

Purpose of this Investigation

The purpose of this investigation was to determine which misconceptions in the earth and space sciences appear to be widespread, and to discover if certain individual characteristics such as gender and race are related to misconceptions held.

The research questions addressed by this investigation were:

1. How prevalent are certain earth and space science misconceptions among students and adults?
2. Do gender, race, educational level, urban versus suburban location, and exposure to an earth science course affect these misconceptions?

Instrumentation

The instrument used in this investigation consisted of 18 multiple choice questions which were drawn from 50 questions that were used in an earlier pilot instrument. Following the format for misconceptions surveys suggested by Gilman, Hernandez, and Cripe (1970), each question had one correct or scientifically acceptable response, one or two distracters which were the misconceptions to be measured, and with the exception of one question, additional distracters to make a total of four alternatives. It was necessary to list four directions (front, back, right and left) as distracters in one question, giving it five alternatives. The additional distracters were written so that, to the uninformed person, they would appear to be just as plausible as any of the other answers.

Procedure

The survey was administered in the spring of 1988 to intact classes of 5th, 8th, and 11th grade students, and to adult students in classes at two universities and one trade school, all located in northwest Indiana and northeast Illinois. The purpose of the investigation was explained to all students before they were given the instrument, and approximately 15 to 20 minutes was allotted for students to complete the survey. The remainder of each class period was then used for a discussion of the survey and misconceptions involved.

Students were asked to provide their gender, race, grade level and type of location of residence (urban, suburban or rural). High school and adult students were asked to note whether they were currently taking, or had taken an earth science class. Students did not write their names on the instrument and only group data was used in the reporting and interpretation of the results of this study.

RESULTS AND DISCUSSION

Results of the survey showed that the participants held many misconceptions in the earth sciences and that some subgroups within the sample were likely to have more misconceptions than others. Common misconceptions were classified into three types: primary misconceptions, secondary misconceptions and functional misconceptions.

The Sample

The sample consisted of 1213 students, 307 of whom were in 5th grade, 237 in 8th grade, and 340 who were high school juniors. The remaining 318 were adults enrolled in classes at regional campuses of Indiana and Purdue Universities (n=226) or at a local trade school (n=92).

The sample can be described as follows:

gender:		race:		location:	
male	51%	white	63%	urban	40%
female	49%	black	16%	suburban	55%
		Hispanic	18%	rural	3%
		Asian	2%		

The sample of Asian (n=24) and rural (n=41) students was considered too small to be included in the statistical reports. Most of the grade school students were selected from schools within two very different types of communities of northwest Indiana: East Chicago, a highly industrialized urban area composed primarily of working class families, and Munster, a suburban community most of whose citizens are employed in managerial or professional occupations. Both universities were regional campuses attended by local citizens who commute to classes. All participants lived either in northwest Indiana or northeast Illinois, a region which is part of the greater Chicago metropolitan area.

Common Misconceptions Revealed by the Survey

A measure of the amount of random guessing for each question can be inferred from the number of responses received by the least popular distracter. Common misconceptions were then identified from erroneous responses which were chosen by the sample more than twice as often as the least popular response. Three types of common misconceptions in this study are defined and identified.

Primary Misconceptions

In six cases a misconception was chosen more often than the scientifically acceptable conception. In this paper, these misconceptions are called primary misconceptions. They are listed in Table 1 in descending order of acceptance.

Table 1. Primary Misconceptions Revealed by the Survey

Rank:	Misconception:	Percent:
1	At 12:00 noon, the sun is directly overhead.	82.4
2	Summer is warmer than winter, because in summer the earth is nearer the sun.	77.6
3	In May, June, and July, the sun sets in the west.	58.6
4	When we have a full moon, people that same night in Australia will have a different phase of the moon	52.9
5	The different phases of the moon are caused by the shadow of the earth falling on the moon.	48.1
6	In each day during summer the amount of daylight is more than the day before.	32.4

Secondary Misconceptions

In many cases, the scientifically acceptable response was the most-chosen response, yet a particular distracter was still chosen twice as often as the least chosen distracter. These misconceptions, referred to in this paper as secondary misconceptions, are listed in Table 2.

Table 2. Secondary Misconceptions Revealed by the Survey

Rank:	Misconception:	Percent:
1	If a crystal can scratch glass, it is a diamond.	44.4
2	We can often see planets at night but only with a telescope or a pair of binoculars.	41.5
3	It is not possible that in the near future Chicago could be severely damaged by an earthquake.	36.5
4	It takes one day for the moon to go around the earth	35.9
5	The terrible floods that occur along a river happen only when snow melts in the spring.	33.6
6	The dinosaurs lived at the same time as cavemen.	32.6
7	Day and night occur because the earth goes around the sun.	19.6
8	It takes one year for the moon to go around the earth.	19.5
9	The moon shines because it is like a star, just bigger.	15.7
10	Earthquakes can be accurately predicted by observing the behavior of wild animals.	15.4
11	We can predict very cold winters by looking at the thickness of fur on some animals in the fall.	12.0
12	The moon shines because it makes light like the sun.	9.5
13	Every night planets are in the same place in the sky.	9.1
14	Day and night occur because the sun goes around the earth.	8.8

Functional Misconception

The following misconception, which was chosen by only 4.7% of the participants was, as expected, the least chosen response for that question. (The other responses being the front, back, and sides of the room.) However, because it is quite common in some classrooms (chosen by 19% of urban fifth graders) and because holding this misconception can greatly interfere with one's ability to function in today's world, this erroneous concept is herein defined as a functional misconception and is listed here.

Table 3. Functional Misconception Revealed by the Survey

Misconception:	Percent:
The direction, north, is straight up.	4.7

Discussion of the Primary Misconceptions

1. At 12:00 noon, the sun is directly overhead. 82.4%

Although many misconceptions are the result of logical reasoning patterns, this misconception seems to be the result of references in the media and erroneous teaching. It was one of the few misconceptions which increased in popularity with age which appears to attest to its being reinforced by the community. In the post-survey discussions many students claimed to have heard of the Tropic of Cancer, however few could explain what it had to do with this concept. [It is recognized that the location of the noon sun is contingent upon the location of the observer; the question is to be thought of as being from the latitude of northwest Indiana.]

2. Summer is warmer than winter, because the earth is nearer the sun. 77.6%

Apparently many students do not understand that the earth's tilt causes the sun to be higher in the sky for part of the year. Although in post-survey discussions students did agree that the warmest part of the day follows that time when the sun is the highest in the sky, most had not transferred that concept to the changing seasons; most had not noticed that the sun is higher in the sky in summer than winter.

3. In May, June, and July, the sun sets in the west. 58.6%

From the latitude of northwest Indiana, sunset occurs closer to northwest than west from May 5th to August 2nd. The misconception is, like the noon sun's being straight up, a culturally promoted misconception; it also increased in popularity with age. In post-survey discussions many students stated that they just assumed that the sun set in the same place every day.

4. When we have a full moon, people that same night in Australia will have a different phase of the moon. 52.9%

All students who volunteered comments spoke to how difficult this concept was. Ault (1984a) noticed the same reaction describing how even science-education graduate students struggle when asked this question. The post-survey discussion centered on two means of solving the problem. One way being to decenter one's spacial perspective, to imagine looking at the earth and moon from various points on the earth and from outer space. The second being a reference to the way a full moon is indicated on a calendar, specifically the absence of any location-specific designation.

5. The different phases of the moon are caused by the shadow of the earth falling on the moon. 48.1%

Kuethe (1963) found that 70% of his subjects had the misconception that the moon's phases are caused by the shadow of the earth. Sadler (1987) found that 37% of his ninth grade students also had this misconception. Forty-eight percent of the participants in this survey subscribed to this belief, but the misconception became more popular with age, and at the college level was accepted by 69.5%, exceedingly close to Kuethe's figure 25 years ago.

6. In each day during summer the amount of daylight is more than the day before. 32.4%

There seems to be an inherent feeling among many persons that because summer is warmer than winter, the length of daylight must be increasing. This in spite of the fact that most students are taught that the first day of summer is the longest day of the year. In one discussion, a particular student, dismayed at the number of students who believed that daylight increases throughout the summer, vociferously proclaimed, "If June 21st is the longest day of the year, they can't get any longer."

Discussion of the Secondary Misconceptions

1. If a crystal can scratch glass, it is a diamond. 44.4%

This is another culturally promoted misconception, however, unlike many of the others, it decreased in popularity with age. The fact that, among students who have had earth science classes, a sizable minority still subscribed to the misconception might be attributed to the fact that a geology laboratory is not always required of geoscience students.

2. We can often see planets at night but only with a telescope or a pair of binoculars. 41.5%
13. We can often see the planets because every night they are in the same place in the sky. 9.1%

During the two months that the survey was being administered, Venus was often the brightest object in the nighttime sky. Even when the moon was visible, Venus was still obvious and upon two occasions formed a striking image near the crescent moon. Both misconceptions, distracters of the same question on the instrument, might be overcome with frequent observations of the night sky.

3. It is <u>not</u> possible that in the near future Chicago could be severely damaged by an earthquake. 36.5%

Northwest Indiana is part of the metropolitan area of Chicago. Although the midwest was the site of North America's largest earthquake, the author has long maintained that few Chicago area residents are aware that earthquakes could do much damage at all to cities located in mid-America. In a case of unfortunate timing for the purposes of this study, the city of Chicago and northwest Indiana had, within the year, felt an earthquake registering 5.0 on the Richter Scale. The quake was front page news and the newspapers once again were referring to the old, but still threatening, New Madrid Fault. Yet, in spite of all the publicity the quake engendered, over one-third of the participants still subscribed to the misconception.

4. It takes one day for the moon to go around the earth. 35.9%
8. It takes one year for the moon to go around the earth. 19.5%

In the same way that many children held to the belief that the sun circled the earth daily, they could be expected to believe that the moon also circled the earth every day. By doing so, a person would be guilty only of what Ault

(1984b) called being "intelligently wrong." Both misconceptions decreased with age as did the misconception about the circling sun, but to a much lesser extent. The two misconceptions above are from distracters of the same question on the instrument. Although not identified as a primary misconception in this paper, the first misconception was chosen by fifth graders twice as often as the scientific conception. Even one in four adults subscribed to it. The second misconception was chosen by many students who said in discussions that they knew that the daily circling was incorrect, but could not "remember" the scientific conception.

5. The terrible floods that occur along a river happen only when snow melts in the spring. 33.6%

Acceptance of this misconception appeared to be related to the location in which the participant lived. The KanKakee River, which flows through northwest Indiana farmland, has had many devastating spring floods. Undoubtedly most rural participants were aware of them, which might explain why they subscribed to the misconception more often than urban or suburban participants. On the other hand, the Little Calumet River forming the northern boundary of suburban Munster is susceptible to flooding after heavy rains of any season. Suburbanites were least likely to choose the misconception.

6. The dinosaurs lived at the same time as cavemen. 32.6%

The media has done its part to reinforce the misconception that dinosaurs lived at the same time as cavemen. Although two-thirds of the participants recognized that as fantasy and chose the scientific conception, nearly one-third still opted for the misconception.

7. Day and night occur because the earth goes around the sun. 19.6
14. Day and night occur because the sun goes around the earth. 8.8

Nussbaum and Novick (1982), Nussbaum (1983), and Wandersee (1985) have shown that student's cognitive development often parallels the history of scientific ideas. Day and night caused by an orbiting sun is such a misconception. The two misconceptions above are from distracters of the same question on the instrument. The second misconception above was shown to be quite common among the elementary students, especially in urban classrooms where it reached 32.4%. The popularity of the first misconception suggests that even though many students learn that the earth revolves around the sun, they have not learned to differentiate the effects of revolution and rotation.

9. The moon shines because it is like a star, just bigger. 15.7%
12. The moon shines because it makes light like the sun. 9.5%

An integral part of understanding the causes of the lunar phases is the cause of moonlight itself. As both misconceptions are variations of the notion of the moon's being luminious, these two misconceptions (which were distracters from the same question on the survey) might be considered to be one misconception--that the moon is luminous. This misconception would then have been subscribed to by more than one in four participants.

10. Earthquakes can be accurately predicted by observing the behavior of wild animals. 15.4%

Many misconceptions about the earth were at one time accepted as the correct conception by informed people; this is a modern case. Judson, Kauffman, and Leet (1987) noted that there are several natural phenomena which have been shown to precede earthquakes including crustal movements, surface tilting, and changes in fluid pressure or in electrical and magnetic fields. They noted that some animals may indeed behave strangely before some earthquakes if they feel minute changes in the earth which are unobservable to humans. Judson et al. believe that while no single predictor is today sufficient, continued close observation of the earth may soon result in a reliable method of accurate earthquake prediction.

11. We can predict very cold winters by looking at the thickness of fur on some animals in the fall. 12.0%

Kimble (1955) noted that the misconception that a cold winter can be predicted by the thickness of fur on some animals in the fall is part of the popular folklore. He observed that mule deer, woolly-bear caterpillars, and squirrels have all been used to predict the severity of a coming winter. Data from this survey show that this misconception is still believed by about 12% of the participants which might be due to the fact that it is still occasionally promulgated by persons on television talk shows. Students also claimed to have heard it from parents and friends.

Discussion of the Functional Misconception

The direction, north, is straight up. 4.7%

This may be the most important misconception discussed in this paper. Although accepted by only 4.7% of the total sample, it can greatly interfere with one's ability to function in today's world and is referred to in this paper as a functional misconception. While generally not prevalent, it tended to be more common among younger, urban, and minoriity children. In urban fifth grade classes, this misconception was chosen by 19% of the students. When in post-survey discussions students admitted to believing that north was up, in almost every case the students holding this misconception claimed that it was created by a teacher. It is certainly reinforced by common phrases such as "up-north" and "down-south."

During the post-survey discussion in a class of preservice teachers, the author pointed to a map of Antarctica and asked which direction on that map was north. One student volunteered that it was toward the top of the map; none of the others had any idea. Similarly, Meyer (1987) noted that many of his undergraduate students believe that rivers must flow "down" from north to south. This misconception is unfortunately reinforced by the fact that as a result of Pleistocene glaciation, most major rivers in the United States do flow southward.

Analysis of the Subgroups

The results contained in this section are the average (mean) number of common misconceptions held by each subgroup of the sample. In this study, a

student has a common misconception only when one of the misconceptions listed in the tables above is chosen. As one of the 18 questions on the instrument did not show any common misconceptions, the maximum number of misconceptions possible for any one person or subgroup is 17.

The results by subgroup are displayed in the tables which follow. The variability of total misconceptions held was much greater within the subgroups than between them. Each subgroup studied had a mean of approximately 6 or 7 misconceptions (of the 17 possible), and each had a range from a low of about 1 or 2 to a high of about 12 or 13.

It should be noted that a smaller number of misconceptions may, but does not necessarily, infer that a concept was better understood. The smaller number of misconceptions may be a reflection of a greater amount of random guessing. Following the results for each subgroup, the average number of correctly identified scientific conceptions will be given.

Table 4. Total Misconceptions Analyzed by Gender

Gender:	N:	Maximum:	Minimum:	Mean:	StdDev:	SKewness:
Male	617	12	0	6.64	2.06	-.115
Female	589	14	1	6.97	1.89	-.043

Results of this study showed that males held significantly fewer misconceptions than females (alpha = .01). These results are similar to those obtained by Za'rour (1975), who in a study of 1444 Lebanese high school and college students, showed that males held fewer misconceptions in science than did females. The means of scientific conception acceptance by gender are: Males 8.57, Females 7.74.

Multivariate analysis showed that black males held more misconceptions than black females. See Table 6 below. There were no discernible patterns whereby it could be stated that one gender had more misconceptions in a particular field, (e.g. astronomy) than the other. Males of all racial groups did appear to understand more scientific conceptions than their female counterparts which is similar to results obtained on NAEP science content questions where males have scored about five percentage points higher than females (Linn, de Benedictis, Delucchi, Harris, & Stage, 1987). Lightman, Miller, and Leadbeater (1987) independently noted from their research that males are more knowledgable than females in the area of astronomy.

Although the difference between males and females was shown to be statistically significant, the author does not believe it to be of much practical importance. This difference is the smallest significant difference between two subgroups in the study.

Table 5. Total Misconceptions Analyzed by Race

Race:	N:	Maximum:	Minimum:	Mean:	StdDev:	Skewness:
White	759	14	1	6.64	2.00	.053
Black	193	11	1	7.10	1.99	-.256
Hispanic	212	12	2	7.18	1.78	-.162

Although white participants were shown to have held fewer misconceptions than blacks, and blacks fewer than Hispanics, a Tukey-b multiple comparison test showed that the differences across race are significant at the 0.05 level only between white participants and the two minority groups. It was found that white participants were more likely to have misconceptions if they were one of those based on popular folklore, such as winters' being predictable by looking at fur of animals, the sun's being straight up at noon, or the June

sun setting in the west. The means of scientific conception acceptance by race are: White 8.87, Black 6.80, Hispanic 6.94.

Table 6. Total Misconceptions Analyzed by Race and Gender

Race/Gender:	N:	Maximum:	Minimum:	Mean:	StdDev:	Skewness:
White male	412	12	1	6.47	2.08	-.058
Black male	83	11	3	7.24	2.03	-.011
Hispanic male	95	11	2	6.82	1.88	-.103
White female	346	14	3	6.82	1.90	.297
Black female	110	11	1	7.00	1.97	-.395
Hispanic female	116	12	3	7.30	1.72	-.167

Results broken down by race and gender show that white and Hispanic females held more misconceptions than white and Hispanic males, however black males held more misconceptions than black females. The means of scientific conception acceptance by gender and race are:

White male: 9.18 Black male: 7.12 Hispanic male: 7.22

White female: 8.50 Black female: 6.56 Hispanic female: 6.73

Table 7. Total Misconceptions Analyzed by Educational Level

Level:	N:	Maximum:	Minimum:	Mean:	StdDev:	Skewness:
5th grade	307	14	1	6.97	1.91	.089
8th grade	237	11	0	7.09	1.95	-.177
11th grade	340	11	1	6.65	1.03	-.203
College	226	12	1	6.43	2.01	.012
Trade	92	12	3	7.00	2.03	-.178

A Tukey-b multiple comparison test on this data showed that the differences across grade level are significant at the 0.05 level only between the college level and the fifth and eighth grades. Fifth graders showed the lowest level of acceptance of scientific conceptions as well as a lower than expected mean of misconceptions, apparently due to more random guessing.

The means of scientific conception acceptance by educational level are: 5th grade 6.76, 8th grade 7.85, 11th grade 8.85, college 9.31, trade school 8.52. Scientific conception results were similar to Lightman, Miller, and Leadbeater's (1987) findings that astronomical knowledge is associated with age and education.

Table 8. Total Misconceptions Analyzed by Location

Location:	N:	Maximum:	Minimum:	Mean:	StdDev:	Skewness:
Urban	488	12	1	7.06	1.88	-.190
Suburban	669	14	0	6.64	2.04	-.027

Urban residents held significantly (alpha = 0.01) more misconceptions than suburbanites. It can be assumed that these results, which were similar to the racial group results, were due in part to the high predominance within the urban area of the two minority groups. The difference in misconceptions by location may be a result of a combination of several factors including social-economic status, racial differences, and perhaps some other factors attributable to the school systems and curricula involved. The means of scientific conception acceptance by location are: Urban 7.28, Suburban 8.78.

Table 9. Total Misconceptions Analyzed by Earth Science Courses Taken Broken down by Grade Level

Level/Course:	N:	Maximum:	Minimum:	Mean:	StdDev:	Skewness:
11th graders						
no earth science	129	11	2	6.77	1.90	-.133
earth science	206	11	1	6.54	2.08	-.244
College students						
none	48	12	3	6.88	2.33	.073
high school only	57	10	1	6.30	2.04	-.237
university only	85	11	1	6.28	1.91	.059
both levels	34	9	2	6.38	1.69	-.367

There was no significant difference (alpha = .01) between the subgroups. The means of scientific conception acceptance are:

11th graders		College students	
no earth science	8.60	none	9.00
earth science	9.02	high school only	9.53
		university only	9.27
		both levels	9.50

One would hope that students who had taken an earth science class would have a better understanding about the earth and space than those who had not. Results from this study show that this is often the case. There were several questions, however, for which those who had not taken earth science did better than those who had. For instance, those who had taken an earth science class were more likely to place the dinosaurs alongside the cavemen.

The author would not have been surprised if those participants who had not taken earth science had actually scored better than those who had. In many high schools, including the two public high schools used for this study, the earth science course is recommended only for those who appear to be academically unable to succeed in the mathematically more rigorous science courses. It is possible, therefore, that those students who opt not to take earth science already understand more about the earth than those who choose to take it. If so, then at the least it might be argued that earth science is being taught to those who need it most.

SUMMARY

Data from this study have verified that misconceptions in the earth sciences are widespread. Six primary misconceptions and 14 secondary misconceptions were identified. In addition one functional misconception is suspected to be common among some subgroups.

Misconceptions are found with great regularity in both males and females, in all racial groups, among urban and suburban students, and across all five educational levels studied. Students who have taken earth science classes have slightly fewer misconceptions than those who have not. Although significant (alpha = .01) differences were found across genders, races, educational levels, and locations, the differences in misconceptions means were smaller than the differences in scientific conception means.

Suggestions for the Science Classroom

Direct observation of natural phenonema can help overcome many of the misconceptions identified in this paper. A student who has watched Venus or Jupiter move above the constellation Orion in the night sky will probably not later believe that planets are only visible with a telescope. A student who has traced the sun across the sky through the course of a day or a year will not believe that the sun is straight up at noon or sets due west every day.

Nussbaum and Novick (1982) emphasized that the first step in an instructional strategy to help students overcome misconceptions should be making the students aware of their own conceptions. For students to be able to alter their misconceptions, they must then believe that their existing conceptions are unsatisfactory. Posner, Strike, P. W. Hewson, and Gertzog

(1982) proposed that for a new conception to be accepted, it must be intelligible, plausible and fruitful.

Classroom discussions can be used to help students create within themselves cognitive dissonance. In all such discussions, students should feel free to express their own ideas and opinions. Teachers can learn much about their students' understanding of natural phenonema though classroom discussions. Teachers can also use this teaching mode to interject comments and questions which may cause students to think more deeply about their own interpretations of events.

As Wandersee (1985) has noted, discussions of the history of science can help students overcome some misconceptions. This strategy is particularly useful for those misconceptions, such as the sun's circling the earth, which were accepted as true explanations by learned people in the past. As students metacognitively understand the thought processes which others went through to discover a new understanding, they may incorporate that understanding into themselves.

For many students, the manipulation of physical materials, as well as discoveries made for themselves, helps in the retention of important information. The author contends that science should not be taught in a vacuum, that all the senses should be used when learning about the natural world, and that relationships between the natural sciences and other disciplines should be emphasized during instruction.

Twenty years ago, Ausubel (1968) proposed that teachers "Find out what the learner already knows and teach him accordingly." (p. 337) This study has shown that most learners have many misconceptions in the earth and space sciences. Designing curricula which begin with students' preconceptions,

while ensuring that students avoid developing additional misconceptions during instruction, should be a primary goal of earth science educators.

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