

## Teaching Future Teachers Basic Astronomy Concepts—Seasonal Changes—at a Time of Reform in Science Education

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**Abstract:** Bearing in mind students' misconceptions about basic concepts in astronomy, the present study conducted a series of constructivist activities aimed at changing future elementary and junior high school teachers' conceptions about the cause of seasonal changes, and several characteristics of the Sun–Earth–Moon relative movements like Moon phases, Sun and Moon eclipses, and others. The activities and results concerning the cause of seasonal changes are reported. Both the experimental class and the control groups improved their grasp of basic astronomy concepts statistically significantly, although the experimental class made the most impressive progress of all. Regarding subjects relevant to this study (seasonal changes), only the experimental class showed a statistically significant improvement, which justifies the constructivist approach. We conclude that in implementing a reform in the science curriculum, the change has to include the subjects taught and also the way they are taught. © 2006 Wiley Periodicals, Inc. *J Res Sci Teach* 43: 879–906, 2006

The Israeli education system underwent a long period of changes as a result of the recommendations of the Tomorrow 98 (1992) report. Among the reforms proposed are the revision of mathematics, science, and technology curricula and the “implementation of a comprehensive program for the pre-service and in-service training” (p. 29) of schoolteachers. One of the main views of that report is as follows:

Today, mathematics, science, and technology are part of the general education needed by every person capable of giving something back to society. We do not claim that everyone has to be a scientist. But every worker, teacher, soldier, musician, farmer, businessman, manager, or politician, or anyone else who works in a place that requires some basic skills, should have certain quantitative and scientific capability, the ability to learn and understand some scientific or technological topics, and an understanding of scientific expressions. . . . There is a need to broaden the scope of mathematics, science, and

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technology teaching for all children, from kindergarten, elementary, and junior high school, and for all non-science high school students. (p. 9)

Similar initiatives on curriculum reform have set ambitious goals to increase scientific literacy among the population. The impetus for reform and the achievement of scientific literacy appears related to such issues as the number and quality of scientists, engineers, and technicians; the technical illiteracy of most high school and college graduates; a worsening shortage of qualified high school science teachers; and declining test scores in science. These initiatives have been influenced by the public's increasing preoccupation with the quality of school science teaching and the apparently falling standards of students' knowledge and understanding of science (Wallace & Louden, 1992). Such developments have appeared in reports from the USA (American Association for the Advancement of Science, 1993; National Research Council, 1996), Canada (Orpwood & Souque, 1985), Australia (Department of Employment, Education & Training, 1989), the UK (Goldsworthy, 1997), and Italy (Borghi, De Ambrosis, & Massara, 1991).

Livanis (2000) went further, speaking of physics teaching:

For the past 130 years, physics has been an integral part of science curriculum at the high school level. Its current vertical position, established about 100 years ago, is now strongly challenged. The national reform movements, . . . and documents such as *A Nation at Risk* (1983), that responded to low science scores and an ever growing gap between science/technology and society, have all been the backbone of Leon Lederman's ARISE (American Renaissance in Science Education) educational reform. Using the theories of hierarchical learning, constructivism, and findings that show that prior knowledge of physics greatly enhances learning in chemistry and that knowledge of chemistry is beneficial to learning biology makes this reform worth examining.

The limited impact of the reforms made in science teaching over the past two decades in different parts of the world has been a subject of considerable interest. Wallace and Louden (1992) concluded that the reform of classrooms must be understood through the "view of the central place of teacher's knowledge in teacher's work" (p. 519). Several recent studies analyzing the results of the reforms in science education in American schools have come to the following conclusions (Dana, Campbell, & Lunetta, 1997; Radford, 1998; Yager, Lutz, & Craven, 1996):

1. Instituting reform in science education requires teachers who are knowledgeable in science content, process, and inquiry pedagogy.
2. Most teachers need training to be able to teach reform-based science.
3. Standards for both teaching and learning science must take into account recent research into constructivist theory and its implementation in the classroom.

According to these premises, a new science and technology program was proposed here in Israel from elementary up to senior high school. One of the new topics included throughout the entire program is "The Earth and the Universe," with astronomy as the core subject.

### The Teaching of Astronomy

Astronomy is the oldest of all sciences. For thousands of years, it has had a great influence on human perception of our surroundings and of ourselves. Astronomy education is currently enjoying a period of curriculum-driven exposure and development after having waxed and waned in popularity over the last 150 years. It had widespread popularity in the latter half of the 19th century (Harris, 1982); however, for much of the 20th century (notwithstanding initiatives such as

Project Physics), astronomy became almost totally excluded from schools (Jarman & McAleese, 1996).

Recently, astronomy and astrophysics have come to play a central role in the natural sciences, with many direct links to other sciences (e.g., many aspects of physics, mathematics, chemistry, and the geosciences). They have an important cultural content including our distant origins, the recognition of the location and restricted extent of our niche in space and time, cosmological considerations, as well as philosophy in general. Its recent successes are largely dependent on advanced technologies and methodologies, such as optics, electronics, detector techniques at all wavelengths, computer techniques such as image processing, and the transfer, storage and retrieval of very large data sets.

Astronomy is undoubtedly among the sciences with the most intense public interest, as testified to by the very large number of popular astronomy journals, planetaria, amateur clubs, and interested individuals in all countries. Trumper (2006) found that the three most interesting physics topics for junior high school boys and girls were “How it feels to be weightless in space,” “How meteors, comets, or asteroids may cause disasters on earth,” and “Black holes, supernovas, and other spectacular objects in outer space.”

Astronomy also has great media appeal, in part because of its exploratory (“adventurous”) character and ability to produce spectacular images. With increasing public awareness of the Earth’s fragile ecosystems and the obvious influence of external, that is, “astronomical,” forces (solar irradiation, variations in the Earth’s orbit, collisions with other bodies, radiative effects from nearby cosmic explosions), this science has taken on a new significance in the minds of many people.

As reported in various countries, such as the USA (Zeilik et al., 1997), New Zealand (Taylor, Barker, & Jones, 2003), Cyprus (Diakidoy & Kendeou, 2001), and Estonia (Kikas, 1998), astronomy education, probably more than other branches of science education, is often characterized by an aggregate view of knowledge that is largely incompatible with current philosophy and practice. Overall, astronomical concepts are presented as facts, with relevant explanations either missing or taking the form of simple statements of causes with no further description of the underlying causal connections. Moreover, the sequence of the presentation does not appear to take into account: (a) the interrelationships that exist among the different concepts; (b) that the acquisition of some concepts may be a prerequisite for the acquisition of others; and (c) that the students may have already formed their own conceptions.

A number of factors contribute to the potential of astronomy as an agent for change in students’ conceptual frameworks:

1. New discoveries in astronomy create interest and can be exploited to increase students’ motivation to learn science.
2. Other research fields in science can be incorporated in, and enriched by, the study of astronomy.
3. The study of astronomy can display the growth of knowledge as a process of developing, discarding, and replacing explanatory models.
4. The study of astronomy can lead to a better understanding of the world in which one lives, just as the study of anatomy leads to a better understanding of one’s body.

The European Association for Astronomy Education has published a declaration summarizing some of the main aims of astronomy teaching (EAAE, 1994):

1. Astronomy education should be started as early as possible in the primary school and progress in the following years. Through the media, students are nowadays exposed to a

- multitude of mainly unstructured impressions from the space sciences and associated areas: the teaching of astronomy in schools will establish the structure and the desirable organizational concepts.
2. By the end of compulsory education, students should have been involved in observation, experimentation, and discussion of the following ideas from astronomy: (a) our place in the solar system, progressing to our place in the universe; (b) the nature of objects we see in our sky, such as planets, comets, stars, and galaxies; and (c) examination of thinking from the past ages and more recent times to explain the character, origin, and evolution of the Earth, other planets, stars, and the universe.
  3. In initial training of teachers and their subsequent in-service training, these ideas should be introduced and reinforced. Recent studies of students' misconceptions and ideas in astronomy provide a useful basis for the further development of teaching methods.
  4. Because astronomy can provide a unique opportunity for fascinating, whole-school activity, support should be provided for optional courses and extracurricular work in astronomy.
  5. Astronomy locates our niche in space and time. Students should be aware of threats, from light pollution and radio interference, to our ability to observe the night sky.
  6. Astronomy teaching conveys the fundamentals of the scientific method, including the associated doubt and lack of answers and the interplay between experiment and theory, thereby forcing students to adopt a critical attitude toward the many pseudosciences.
  7. Astronomy knows no national frontiers—the sky is the same above all—and the teaching of astronomy therefore contributes to international collaboration between students and teachers everywhere.

### Students' Conceptions of Basic Astronomy Concepts

According to the constructivist perspective, humans are seen as subjects who actively construct understanding from experiences using their already existing conceptual frameworks (Vosniadou, 1991; Wubbels, 1992). What a student learns, results from the interaction between what is brought to the learning situation and what is experienced while in it. In many cases, students' naive notions are often misconceptions, or alternative frameworks, which may impede learning of appropriate concepts in the field despite the best efforts by instructors (Redish & Steinberg, 1999).

Science educators have recommended the use of conceptual change approaches in science education (e.g., Hewson & Hewson, 1984; Stofflet, 1991). Conceptual change pedagogy is based on constructivist learning theory, recognizing that powerful theories are brought to the classroom and affect the learning of new material (Stofflet, 1994). This instructional approach holds that learners must first become dissatisfied with their existing conceptions, in addition to finding new concepts intelligible, plausible, and fruitful, before conceptual restructuring occurs (Posner, Strike, Hewson, & Gertzog, 1982).

High school, college, and university students' notions of astronomy concepts have been investigated far less than those of elementary school students, which have been researched extensively during the last 30 years (e.g., Baxter, 1989; Jones, Lynch, & Reesink, 1987; Klein, 1982; Nussbaum, 1979; Nussbaum & Novak, 1976; Sharp, 1996; Sneider & Pulos, 1983; Vosniadou, 1992; Vosniadou & Brewer, 1992, 1994).

Lightman and Sadler (1993) found that students in grades 8–12 shared some of the conceptions held by elementary school children. Although more than 60% of the students held the accepted scientific concept about the day–night cycle, less than 40% knew the correct characteristics of the Moon's revolution. Furthermore, less than 30% had the right conception

about the phases of the Moon, the Sun overhead, and the Earth's diameter, and only 10% knew the reason for seasonal changes.

Zeilik, Schau, and Mattern (1998) investigated the conceptions of science and nonscience university majors on several physical and astronomical concepts. They found that, before entering an "Introduction to Astronomy" course at the university, only 10% of the students held the correct view of the Moon's rotation, 23% had the right conception of the Sun overhead, and about 30% knew the accepted scientific explanation of the phases of the Moon and the solar eclipse.

Very few studies investigating teachers' astronomy conceptions have been carried out. Bisard, Aron, Francek, and Nelson (1994) assessed suspected science misconceptions, including some astronomy conceptions, held by groups of students ranging from middle school through university. Regarding the astronomical topics separately, the main findings of these researchers were as follows:

1. Students generally performed quite poorly when asked about the Sun's position in the sky at specific times of the day and year.
2. Slightly fewer than 40% of all students correctly replied that the different phases of the Moon are caused by reflected sunlight.

Trumper (2001) carried out an assessment of students' basic astronomy conceptions from junior high school through university. He summarized the most widespread misconceptions at all educational levels (Table 1).

Moreover, he found that university students, even if they did not study physics, achieved the highest correct response rate (51%), very similar to that obtained by senior high school physics students. The correct response rate of senior high school students was somewhat higher (44%)

Table 1  
*Most widespread astronomy misconceptions by groups (in percentages)*

Subject	Misconception	Junior High School	Senior High School	Future Primary Teachers	Future High School Teachers	Non Science University
Day-night cycle	Earth moves around the Sun	36	30	51	37	34
Moon's phases	Moon moves into Earth's shadow	19	27	16	25	29
	Moon moves into Sun's shadow	25	17	29	23	16
Reason for seasons	Earth closer to Sun in summer	45	33	37	32	32
Reason for it being hotter in summer than in winter	Earth closer to Sun in summer	36	28	20	19	22
	Earth's rotational axis flips back and forth	20	23	31	29	23
Sun overhead at noon	Everyday	35	36	48	44	42
Moon's phase in solar eclipse	Full phase	74	77	71	75	70
Moon's rotation—same side visible	Moon does not rotate on its axis	54	57	51	47	50

than that of future high school teachers (40%), but the same as that achieved by future high school science teachers. Future elementary school teachers got the lowest correct response rate (32%), even lower than that scored by junior high school students (36%). This suggests that future elementary teachers have more misconceptions about basic astronomy concepts than typical junior high school students.

### Constructivist Attempts in Teaching Astronomy

The public interest in astronomy seems to have grown since the upsurge of media reports of the different satellites and shuttles taking part in space research. In parallel, astronomy is being increasingly introduced in the school curriculum in different countries, including Israel. Nevertheless, very few teachers venture to teach astronomy because they lack the necessary knowledge and training; the majority of elementary and junior high school teachers have not studied astronomy in school or in college. Moreover, learning astronomy demands abstraction capabilities and an extensive understanding of space and time concepts or, alternatively, ways of teaching that explain phenomena as concretely as possible. These requirements increase teachers' lack of confidence and reluctance to teach astronomy.

Vosniadou (1991) held it is important to design curricula and instruction that aim at increasing students' conceptual awareness. Students often find scientific explanations incredible and see no reason why they should question their beliefs, which are more consistent with their everyday experience.

In this constructivist spirit, Bisard and Zeilik (1998) found that allowing student groups to work on an activity for 10–15 minutes each class period could be very productive if the activity is well structured and not too easy. In such a way they restructured their classes as what they called “conceptually centered astronomy [classes] with actively engaged students,” reporting significant students' conceptual changes (Zeilik & Bisard, 2000).

Morrow (2000) proposed and performed kinesthetic astronomy lessons in which, through a series of simple body movements, students gained insight into the relationship between time and astronomical motions of the Earth (rotation about its axis, and orbit around the Sun), and also about how these motions influence what we see in the sky at various times of the day and year. A complete description of the activities performed by Morrow's classes can be found at [http://www.spacescience.org/Education/ResourcesForEducators/CurriculumMaterials/Kin\\_Astro/ST\\_112700.pdf](http://www.spacescience.org/Education/ResourcesForEducators/CurriculumMaterials/Kin_Astro/ST_112700.pdf).

Diakidoy and Kendeou (2001) reported on a study they carried out with fifth grade students learning astronomy concepts such as the Earth's shape and rotational movement, and the day–night cycle. In the activity dealing with the day–night cycle students were asked to express their ideas, and the cycle was demonstrated with the use of a balloon and a flashlight. Their study showed that students who received experimental constructivist instruction of target astronomy concepts demonstrated significant improvement in their understanding and learning of these concepts, in contrast to students who received standard, textbook-based instruction.

Bakas and Mikropoulos (2003) developed an educational tool based on the technologies of virtual reality. The objective of this virtual environment was to create an interactive learning environment within which students aged 12–13 years were able to come into immediate contact with the movements of the planets and the Sun and the phenomena occurring in our solar system, in particular the Earth–Sun system. The researchers' findings showed that, after the interaction with the virtual environment, students created fewer, more concrete, and scientifically accepted mental models.

### The Present Study

Bearing in mind the misconceptions that have been observed in the foregoing research studies, the purpose of the present study was to carry out a series of constructivist activities to change future elementary and junior high school teachers' conceptions about the reason for the seasonal changes, and several characteristics of the Sun–Earth–Moon-relative movements like Moon phases, Sun and Moon eclipses, and more. The activities and results concerning the cause of seasonal changes are reported.

#### *Sample Characteristics and Research Methods*

We carried out a research project with 138 university and college students, divided into four different classes, all of whom were studying introductory courses on astronomy for the first time in their lives. The experimental class comprised 19 junior high school technology teachers learning a semester-long course in their retraining for science teaching in primary and junior high schools in the framework of their bachelor of education studies at an academic college of education. There were three different control classes, which learned in the traditional lecture-based way, including use of audiovisual materials with computer animations and simulations, coupled with the use of demonstrations given by the lecturer: one comprising 83 university students in a semester-long course in the Interdisciplinary Department of the Faculty of Humanities, 14 future high school physics teachers taking a semester course in the framework of their bachelor of science studies in the Physics–Mathematics Teaching Department of the Faculty of Science and Science Education at the same university, and 22 future primary school teachers taking a 1-year-long course in their training for science teaching in Bedouin primary schools as part of their teaching certificate studies at the same academic college of education as the experimental class.

The astronomy conceptions of the students were analyzed by means of a written questionnaire containing 21 questions presented to them at the beginning of the course. Five experts in physics education research and three experienced lecturers in “Introduction to Astronomy” courses judged the content validity of the questionnaire. After some minor changes, as suggested by the judges, the test was deemed valid (see Appendix). Cronbach’s alpha coefficient for reliability was found to be 0.62, a relatively high score considering that different questions were related to different astronomy concepts and understandings. Furthermore, we performed an item analysis that provided discrimination indices measuring the extent to which the test questions differentiated between students with the highest and lowest scores on the total test. All the questions discriminated positively, and for most of them the discrimination indices were in the range of 0.18–0.62 with respect to the upper and lower quartiles of the sample, and 0.31–0.76 with respect to the upper and lower 10% of the sample. To acquire a more in-depth understanding of students’ conceptions, four students from the experimental class volunteered to be interviewed according to the principles of the “clinical interview” (Osborne & Gilbert, 1980). The students were interviewed twice: the first time after they completed the pretest questionnaire and the prediction of the Sun’s path in sky, and the second time after they handed in their homework. In these interviews, the researcher played an unbiased role, trying to clarify and get a better comprehension of students’ conceptions underlying their answers to questions dealing with the seasons; they were unstructured interviews that began with the researcher asking students to explain their written answers in a more extensive way and then students were able to raise any idea they wanted while the researcher followed them trying to understand their meaning. The interviews were tape-recorded and fully transcribed.

For example, one of the students answered on the pretest questionnaire that the longest daylight period in Australia is in September (correct answer: December), and he was asked by the



researcher to explain his response (Why do you think the longest daylight period in Australia is in September?). During the interview, the student realized alone that the longest daylight period in Israel is in June and there is a difference of 6 months between us and the southern hemisphere, so he corrected his answer.

### *Experimental Instructional Activities*

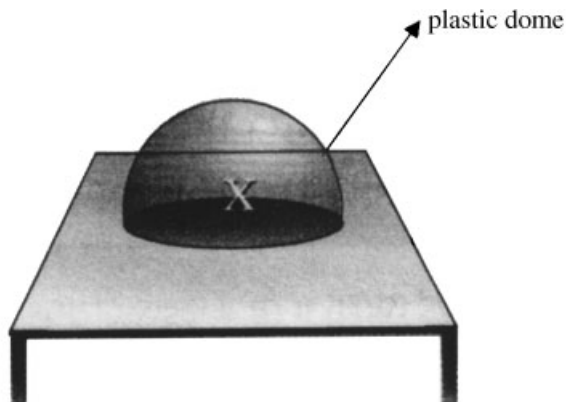
The key aspects of constructivism that influenced the materials and activities for developing students' understanding can be expressed as the need: (a) to have knowledge of students' existing understanding in the targeted conceptual areas, and to use this as a starting point for the design of appropriate teaching materials; and (b) to provide experiences that will help students to change their views and conceptions, and accept the scientific view.

We kept to the general trend proposed by Vosniadou (1991) in science teaching in general, and particularly in astronomy. Aiming to replace well-established beliefs with a different explanatory framework, our experimental instructional activities tried to:

1. Create some conditions for students to question their entrenched beliefs. Putting students in circumstances where they have to evaluate empirical evidence that is contrary to their beliefs can accomplish this.
2. Provide a clear explanation of scientific concepts, preferably in the form of conceptual models or analogies.
3. Demonstrate how the new conceptual models provide a better account of the available empirical observations than the entrenched beliefs.

The study began at the start of the semester, after the students completed the pretest questionnaire, and ran for 3 months including only three periods of 45-minute classes. Most activities were assigned to the students as homework. The experimental instructional procedure was designed to be flexible and to proceed according to the students' time availability. In the first activity, on February 16, 2003, students were asked to predict the path of the Sun in the sky during the day, marking a line representing its position on a clear plastic dome, as depicted in Figure 1, from sunrise to sunset through noon. The plastic dome represented the sky and the observer "stood" exactly at the center of the dome basis (the "X" position in Figure 1).

After a short class discussion, the students were assigned a series of once-weekly homework activities for 2 months:



*Figure 1.* The plastic dome.



1. Tracking the Sun's path in the sky: This activity allowed students to track the apparent motion of the Sun in the sky on a model in which the plastic dome represented the sky. To do this, they had to mark on the same dome they used in class the positions at different hours of the day that cast a shadow on the same central spot (X). For this activity, an outside level spot had to be picked that was not to be in shadow at any time during the day, and the dome had to be fixed on a piece of stiff cardboard. Using the compass, students had to mark a north-south arrow on a corner of the cardboard, trace its outline on the ground so that its position could also be verified before each observation, and anchor it with a brick to prevent it from blowing away. Students were asked to write answers to several questions after completing the activity: What sort of path does the Sun follow in the sky? Did the Sun travel directly over the top of the dome? Where did the Sun begin in the morning? Where was it in the afternoon? What about at noon? At midday? At sunset? How does the Sun's path change during the different observations? How do these paths compare with your prediction?
2. Tracking the Sun's shadows: Each student had to mount a short yardstick in clay at the edge of a piece of stiff cardboard and outline the yardstick position with a marker. They had to place the cardboard parallel to the plastic dome cardboard, trace its outline, and anchor it also with a brick to prevent it from blowing away. Students had to mark the position and tip of the shadow of the yardstick at regular intervals throughout the day, noting the time of each observation on the same days they tracked the Sun's path (Figure 2). After a day of recording, students had to connect the shadow ends recorded near noontime with a line (if not measured, the locations of the noon and midday shadows could be estimated from the positions of shadows marked at nearby times). If a computer was available, the length of each day's shortest shadow had to be measured and entered, along with its time, onto a spreadsheet or graphing program. Students had to make a computer or hand graph relating the shortest shadow length to the day of each observation. Students were asked to write answers to several questions after completing the activity: How do shadow lengths change during the day? Why do they change? Is there a pattern as to where the shadows fall and their lengths? Why is there a pattern? Is the Sun directly overhead at any time? Why is the shortest shadow around noon? Why does the shortest shadow point north? Does the time of the shortest shadow remain constant or does it change? Is there any relation between these measurements and the Sun's path in the sky?
3. Recording daily temperatures: From newspapers or broadcast newscasts, students had to collect local high and low temperature readings for each day, on which they performed the above activities, and plot them on a graph. Students were asked to write if they found some correlation between the temperature measurements and the shadow stick and dome measurements.
4. Tracking sunrise and sunset times: From the appropriate internet address ([http://aa.usno.navy.mil/data/docs/RS\\_OneYear.html#formb](http://aa.usno.navy.mil/data/docs/RS_OneYear.html#formb)), students had to collect the sunrise and sunset times on each of the days they performed the previous activities, by

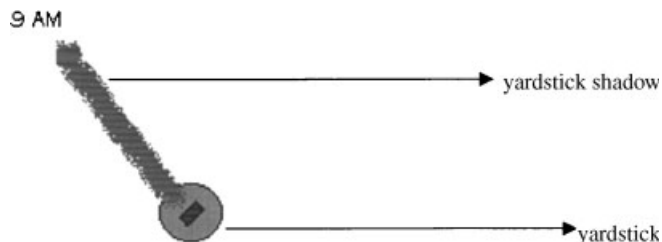


Figure 2. Tracking the Sun's shadows.

pointing out the exact longitude and latitude of their location, and plot them on a graph. They were also asked to plot on a graph the number of daylight hours each day. Students were asked to write if they found some correlation between the number of daylight hours and the temperatures, the shadow stick, and the dome measurements.

Toward the end of the students' homework observations, a 45-minute class was dedicated to examining how an angle spreads a flashlight beam. Every pair of students took a sheet of graph paper attached to a piece of hard cardboard, held it perpendicular to the table in a darkened room, and shone the flashlight directly onto the graph paper from the side, about 1 meter away (Figure 3), holding the flashlight parallel to the table. They were asked to trace the outline of the flashlight's beam on the graph paper, and then, maintaining distance from the paper to the flashlight, to swivel the board toward and away from the flashlight at different angles, and trace the outline of the flashlight's beam on the graph paper. By counting the squares on the graph paper enclosed or partially enclosed by the circle of light, they were able to quantify their observations. After the students made their measurements, a discussion was held in an attempt to answer several questions: Does the area of the beam on the paper increase or decrease when the board is tilted toward and away from the flashlight? Does the illuminated spot on the graph paper always remain the same size? When is it larger? Smaller? Is the spot always the same brightness? When is it brighter? Fainter? The next activity explored just this question using the closest star, the Sun.

On that day, May 4, 2003 (a very sunny day), we examined this "spreading out" of light by measuring how quickly and how much sunlight can warm two sheets of paper, one tilted, one not. At the beginning of the previously described activity, we went outside with the students and placed two pieces of stiff cardboard with thermometers on the ground (Figure 4). We tilted one board to face the Sun and have the Sun's rays fall nearly perpendicular to it. The other was almost flat on the ground (actually, tilted slightly away from the Sun). We recorded the initial temperature of the thermometers, 30°C, and did so again about 20 minutes later. The thermometer of the board facing the Sun's rays nearly perpendicularly showed 62°C and the other one 53°C. Further discussion was held in class, connecting the results of the last two activities.

On May 18, 2003, students handed in their homework and performed the last activity, called "The angle of Sun's light rays relative to the ground at different Earth positions." In it they were presented with two different pictures of models, one of them with the rotational axis of the Earth perpendicular to the plane of its path around the Sun and the other with the rotational axis of the Earth tilted at an angle of 23.5° (Figure 5). For both models they were asked a long series of questions that were intended to lead them to the conclusion that only the tilted model could explain the seasonal changes, based on the measurements they had taken at home and in class.

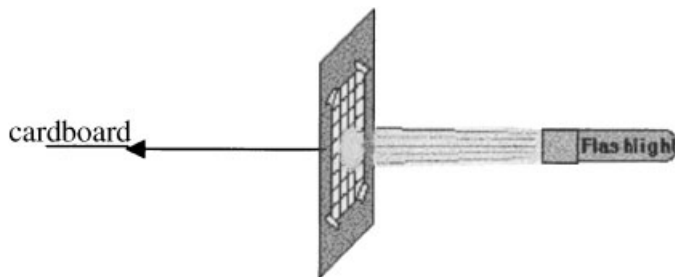


Figure 3. Tracking the outline of a flashlight on a graph paper.

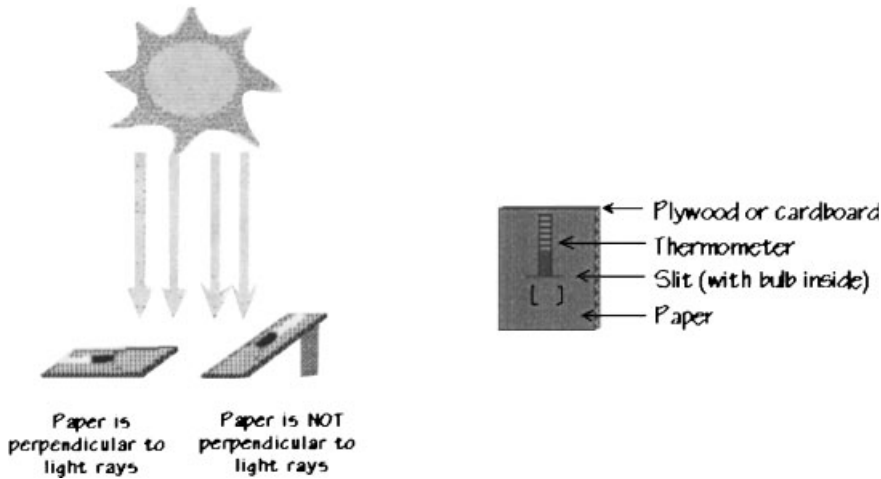


Figure 4. Measuring the temperature change of two identical pieces of stiff cardboard on the ground.

## Findings

### *Pretest and First Interviews Results*

Figure 6 shows the extent of success—that is, the mean percentage of correct answers of the different groups in answering the whole pretest questionnaire, and the mean percentage of correct answers to questions about phenomena related to seasonal changes (questions 1, 6, 8, 9, 14, and 15)—at the beginning of the introductory astronomy course.

In the whole questionnaire, there was a statistically significant difference between the success of the university students and of all the other groups, with the largest effect size for the future Bedouin primary school teachers (Cohen, 1988) (Table 2), and for the seasons' questions we found a statistically significant difference only between the university students and the future Bedouin primary school teachers (Table 3).

In the interviews, students' expressed uncertainty and were not able to fully explain their pretest questionnaire responses as to whether they were correct or wrong, as indicated in the following excerpts (R, researcher; Sn, student number n):

S1—Question 9 (Students' answer in questionnaire: On the Fall equinox the Sun sets in the west. A week later it will set in the same place—Correct answer: A week later it will set southward to the equinox position).

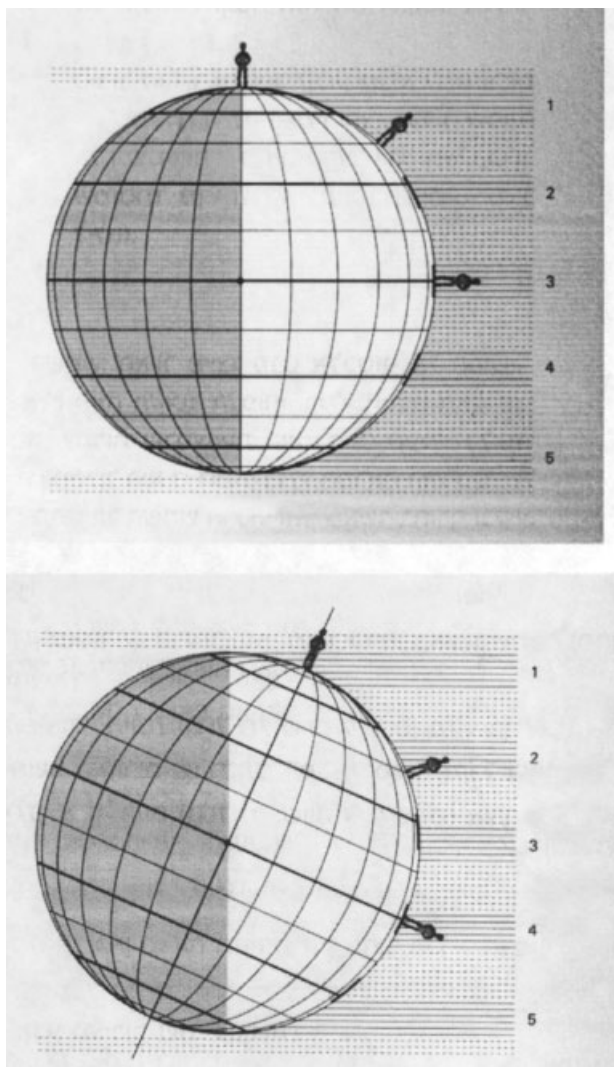
R: You wrote the Sun sets in the same place on the fall equinox and a week later; please explain to me your answer.

S1: I'm not so sure about my answer . . . I think the Sun will set southward of the equinox position, because of the Earth's movement around the Sun in an elliptic path . . . The sunset position is always changing.

R: Because of the elliptic path of the Earth around the Sun?

S1: Yes, I think the Sun will set southward of the equinox position.

S2—Question 6 (Students' answer in questionnaire: The main reason for it being hotter in summer than in winter is that the Earth's axis points in the same direction relative to the stars, which is tilted relative to the plane of its orbit—This is the correct answer).



*Figure 5.* Two pictures of models, one with the rotational axis of the Earth perpendicular to the plane of its path around the Sun and one with the rotational axis of the Earth tilted.

R: You wrote that the main reason for it being hotter in summer than in winter is that the Earth's axis points in the same direction relative to the stars, which is tilted relative to the plane of its orbit; I would want to hear more about that.

S2: Let's say that the Sun moves in this way. . . . This part of Earth gets hot, like a pot effect, or something like that. . . . So when we get to the other side it will be winter.

R: How is this related with a tilted axis of the Earth?

S2: I don't know exactly, it sounds logical.

S3—Question 6 (Students' answer in the questionnaire: The main reason for it being hotter in summer than in winter is that the Earth's rotational axis flips back and forth as the Earth moves around the Sun—Incorrect answer).

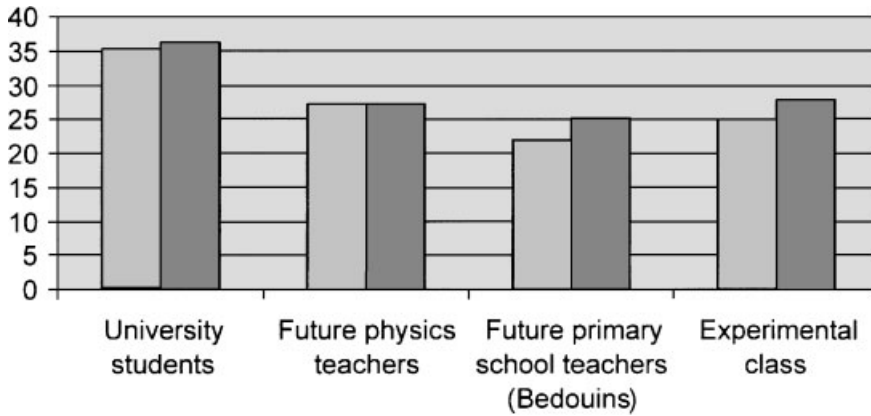


Figure 6. The extent of success (in percent) of the different groups in the pretest. Lighter bars: whole questionnaire; darker bars: seasons questions.

- R: You wrote that the main reason for it being hotter in summer than in winter is that the Earth's rotational axis flips back and forth as the Earth moves around the Sun; I would want to hear more about that.
- S3: I answered this way: It is not A and not B; the distance doesn't change. It also cannot be that the Sun gives off more energy in the summer than in the winter. So I had to choose between C and D. Because . . . I chose C since there are days when we go from fall to spring, so we also have days when the daylight period is the same as the non-light period, so there is a change in the angle.

### *Predictions of the Sun's Path in the Sky*

After the students marked a line representing the Sun's position on the plastic dome from sunrise to sunset through noon, they were asked to write answers to the following questions: Where does the Sun rise and where does it set? Where is the Sun in sky at noon? How many daylight hours are today (February 16, northern hemisphere)? Their answers were as follows:

- Fourteen students wrote that the Sun rises directly east, four pointed to a sunrise position left (north) of east, and one gave a position south of east (the correct answer).
- Fifteen students wrote that the Sun sets due west, and four pointed to a sunset position south of west (the correct answer).

Table 2

*Statistically significant difference between the university students and all other groups in the whole pretest questionnaire*

	Students' Success (Mean)	<i>t</i> -test	<i>p</i> -value	Cohen's Effect Size ( <i>d</i> )
University students	35.1	—	—	—
Future physics teachers	27.2	1.862	0.004	0.488
Future primary school teachers (Bedouins)	21.8	4.048	<0.001	0.872
Experimental class	24.8	3.048	0.002	0.684

Table 3

*Statistically significant difference between the university students and all other groups in questions dealing with seasons in the pretest questionnaire*

	Students' Success (Mean)	<i>t</i> -test	<i>p</i> -value	Cohen's Effect Size ( <i>d</i> )
University students	36.3	—	—	—
Future physics teachers	27.1	1.544	0.07	0.397
Future primary school teachers (Bedouins)	25.0	1.962	0.03	0.548
Experimental class	27.8	1.648	0.06	0.382

- (c) Seventeen students wrote different expressions indicating that the Sun is directly above us at noon (e.g., in the middle between east and west, up in the center [of the dome], up above our heads, in the middle of the sky, up above), and two students pointed to the Sun's position at noon south of the center (the correct answer). One of these two students wrote that the Sun rises south of east and sets south of west; the other pointed to sunrise north of east and sunset south of west.
- (d) Thirteen students wrote that there were exactly 12 daylight hours, one about 12 hours, one between 12 and 13 hours, one about 13 hours, and the last student wrote that it depended on the season.

In sum, only one student was able to predict correctly the path of the Sun in the sky during the day, and no one knew that in winter there are less than 12 daylight hours.

In the interviews the students tried to confirm the validity of these answers from their personal experience as shown in the following excerpts (R, researcher; Sn, student number n):

S1 (Student's answers: the Sun rises in the east, it sets in the west, and at noon it stands in the middle of the sky; there are 13 daylight hours.)  
 R: Please explain to me your answer about Sun's path in sky.  
 S1: The Sun always rises east and always sets in the west.  
 R: What happens at noon?  
 S1: The Sun is always in the middle of the sky.  
 R: Is that why you wrote that the Sun casts no shadow?  
 S1: Yes.  
 R: But you wrote in the questionnaire that . . .  
 S1: There is some inclination, but in certain periods only . . . . If we talk about this period of the year, there are several months in which the weather changes and this is related to the elliptical path of the Earth [around the Sun]; then there is a slight deviation of the Sun.  
 R: What about the daylight hours at this stage of the year?  
 S1: About 13 hours.  
 R: Why 13 hours?  
 S1: I can tell you that in Holland there are more daylight hours.  
 R: Do you mean that more than half a day we have daylight hours?  
 S1: We can say that daylight hours are from 6:00 a.m up to 7:00 p.m. In Europe it is up to 10:00 p.m.  
 R: So what will it be like in summer here?  
 S1: Many more daylight hours.

S4 (Student's answers: the Sun rises north of east, it sets south of west, and at noon it stands south from the center of the sky; there are 12 daylight hours.)

S4: The Sun rises north of east. I see it north of east. When I look out from my house I always see Mount Tabor and I see the Sun rising north of it, not from the middle of the mountain.

R: Mount Tabor is located north of your house?

S4: No! Due east.

R: Where does the Sun set?

S4: South of west. This is what I see.

R: It follows a diagonal path?

S4: Yes!

R: Where is the Sun in the sky at noon?

S4: Slightly south of the center of the sky. I don't see it right above me . . . . When I stand on the balcony and I look at the Sun, so . . . . No, it has to be in the center. I think that I look at the Sun a little after noon. Yes, the Sun stands in the center of the sky at noon.

R: What about the daylight hours?

S4: On a sunny day there are 12 daylight hours. On a cloudy day there are less than 12 daylight hours.

### *The Spreading of a Flashlight Beam and Sunlight at Different Angles*

In this activity students arrived at the expected conclusion that, when the flashlight beam "hits" perpendicular to the paper, the light spreads on a small area and then the light of the illuminated spot is brighter; the area of the beam on the paper decreases when the board is tilted and the illuminated spot is fainter. Next the students confirmed their conclusion by measuring the temperature change of two identical stiff pieces of cardboard on the ground, tilted perpendicularly and non-perpendicularly to the Sun's rays, as described earlier.

### *Tracking the Sun's Path in the Sky*

Students tracking correctly the Sun's path in sky were expected to obtain the following conclusions:

1. The Sun's path is *always* in a southern position with respect to us, changing to a more northerly one when passing from winter to spring and summer.
2. The Sun is never above our heads at noon; it is always south of us.
3. Before the spring equinox, the Sun rises and sets southward to east and west, respectively.
4. After the spring equinox, the Sun rises and sets northward to east and west, respectively.

We first summarize the tracks as drawn by students on the domes:

- Five students drew six or seven paths at different dates, including a correct follow-up to the extremes (sunrise and sunset). The tracks showed that the Sun's paths in the sky are always south of us, but every time in a more northerly position.
- Four students drew four or five paths on different dates correctly, but they dragged the extremes to the center; that is, sunrise exactly east and sunset exactly west.
- Three students drew four or five paths on different dates correctly, without extremes.
- Three students drew two paths on different dates correctly, with uncertain extremes.



- Three students drew four or five paths on different dates correctly, without extremes, but they did not align the dome to the north correctly.
- One student drew seven paths on different dates, including an apparently correct follow-up to the extremes, but he did not align the dome to the north correctly.

After tracking the Sun's path in the sky, students were asked to compare it with their initial prediction. We quote some sentences written by students who drew correct tracks, as just described. Only one student referred to the whole path including the extremes (sunrise and sunset position):

There was a problem with my prediction where the Sun rises and where it sets. I thought that the Sun always rises and sets south of east and of west, and this is a mistake since this position moves towards north of east and of west, respectively.

Other students wrote about the Sun's paths they tracked without referring to the extremes:

In my prediction I drew the path of the Sun in the sky as if it was always in the same place. After the activity, I found that the path changes its direction from winter to summer. The path I drew is a misconception (east-center-west). The Sun's path changes all the time.

My prediction was wrong since I drew the Sun's path up above our heads at noon (in the middle of the sky). The paths I got after the measurements show that the Sun's paths is south of us and with time it changes to a more northern path.

After ending their measurements students were asked several questions; their answers show that most of them realized where the Sun's path is located and how it changes, including the position of the Sun in the sky at noon, but they did not get to the correct conclusion with respect to the sunrise and sunset positions.

- *What is the sunrise position? Is it permanent or does it change?* Eleven students wrote that the Sun rises due east and eight students indicated that the sunrise location is north of east. Eight students claimed that these positions are permanent and 11 students stated that these locations move to the north.
- *What is the sunset position? Is it permanent or does it change?* Eleven students wrote that the Sun sets due west and eight students indicated that the sunset location is north of west. Eight students asserted that these positions are permanent and 11 students stated that they move to the north.
- *Where is the Sun in sky at noon? Is it a permanent position or does it change?* Sixteen students wrote that at noon the Sun is in a south position in the sky relative to us, and two students pointed out that it is directly above us. Six students claimed that this position is permanent and 13 students stated that it moves from south to north.

In the student number 1 (S1) interview we found a contradiction between his answers and explanations. For example, when he talked about the sunrise and sunset locations:

R: Let's see, what were your answers after tracking the Sun's path in sky? First of all, you were asked to compare your prediction (a straight line in the middle of the dome) with the actual tracking.

S1: My prediction was wrong. The actual tracking connects east to west, not exactly from east to west, since it goes from this side [east]—a little bit to the north—to the other

- side, it cuts the line I predicted and goes back to the north [in sunset]. As the days went by the line tracked moved from south to north.
- R: You began your measurements in winter. What happened to the Sun's path in sky when the days went by?
- S1: The path moved toward the middle of the dome, but it will never get to it.
- R: Okay, where was it at the beginning?
- S1: South to us.
- R: And what happened then?
- S1: It moved northward.
- R: You were also asked about the sunrise position.
- S1: The Sun rises east and sets west.
- R: You were also asked if this position changes or remains the same every day and you wrote that it doesn't change.
- S1: I know there are some slight deviations. How can I explain it to you? From the measurements we did we saw there is a slight deviation to the north, but no one can notice it. Generally we can say that the Sun sets in the west.

### *Tracking the Sun's Shadows*

Together with the previous activity, students tracked the Sun's shadows during the day, mainly around noon, recorded the shortest shadow of each day on a table, and plotted a graph relating the shortest shadow length to the day of observation. Students were asked several questions, and their answers were as follows:

- *How do the shadow lengths change during the day?* Fourteen students answered that the shadows are long in the morning, get shorter toward noon, and lengthen again in the afternoon. Five students wrote a similar answer but their description referred only to noon hours.
- *Why do shadows' lengths change?* All the students answered that the cause of the change is related to Sun's position in the sky during the day.
- *Is there a pattern in where the shadows fall and their lengths?* Seventeen students wrote an affirmative answer and two students did not answer the question.
- *Why is there a pattern?* All the students wrote that the reason is that the Sun rises in the east and sets in the west.
- *Is the Sun directly overhead at any time?* Fifteen students wrote a categorical negative answer. Four students were more cautious, writing that it had not happened in their measurements, but it could happen sometime.
- *Why does the shortest shadow point north?* All the students answered that it is because the Sun in the sky is in a southerly position relative to us.
- *Why does the shortest shadow come out around noon but not exactly at 12:00?* Four students answered that at noon (not 12:00) the Sun is exactly south of us, so the shortest shadow appears, and that noon is midday. Three students wrote that Israel is in a geographical position in which, at 12:00 noon, the shadow begins lengthening. Other answers were: "Because not always at noon (12:00) is the Sun in its highest position in the sky"; "The Sun is exactly south of us so we get the shortest shadow"; "Geographically, in Israel we can see the shortest shadow at noon"; "It depends on Earth's position relative to the Sun"; and "The Sun's position in the sky."
- *Does the time of the shortest shadow remain constant?* Seventeen students answered that the time of the shortest shadow changes. One student wrote that the time remains almost constant and one student did not answer the question.

- *Is there any relation between these measurements and the Sun's path in the sky?* Seven students answered that the shadow's length shortens and the Sun's path moves north when we pass from winter to spring and summer. Three students answered that in winter we get a longer shadow than in summer, and during the day the Sun's angle relative to us changes and the shadow undergoes a V turn (the shadow's length and direction change). Three students wrote a short answer, namely that in winter we get a longer shadow than in summer. Two students wrote that the Sun's shadow shortens significantly when we pass from winter to summer because the Sun is in a higher position in sky. Two students answered that the shadow shortens in the passage from winter to spring and summer, and that this change is related to the Sun's path in the sky because the path moves north. One student wrote that in winter the Sun's shadow is longer than in summer, and this is related to the Sun's angle in the sky. Finally, one student did not answer the question.

### *Recording Daily Temperatures*

The students recorded the local high and low temperature readings for each day; on the same days they performed the previous activities and plotted them on a graph. Afterwards, they were asked to find some correlation between the temperature measurements, the Sun's shadows, and the Sun's path measurements. Only 12 students answered the question and 3 of them formulated it in an acceptable way:

There is a correlation. As the shadows get shorter the temperatures get higher. There is also a correlation between the temperature and Sun's path: when the Sun's path moves to a northern position the temperatures get higher, and this is because of the change of the Sun's angle relative to Earth. When the angle becomes wider, the temperature goes higher. The low and high temperatures are on an increasing trend. The Sun's path becomes longer and moves to a more northerly position. During this time Sun's shadows shorten. In the passage from winter to spring and summer, the daylight hours increase, the shadows become shorter, and the temperatures become higher.

It seems that eight students did not succeed in distinguishing between causes and effects:

- There is a correlation; when the temperatures get higher the Sun's shadows become shorter at noon. Regarding the Sun's path, when the temperatures become higher the Sun is located in a more northerly position, and as this happens the Sun's shadows become shorter (four students).
- Yes, there is a correlation with the passage from winter to spring and summer. Temperatures get higher, the Sun's path is nearer to the center of the sky, and the Sun's shadows get shorter (two students).
- As the temperatures get higher the shadow's length gets shorter when we are around noon. As temperatures rise, the Sun's path moves to a northern position; that is, the angle is perpendicular above our heads, so the shadow's length shortens (one student).
- As the temperatures get higher, the shadow's length shortens and the number of daylight hours increases (one student).

Finally, one student formulated an answer that did not indicate what he actually understood:

- Yes, there is a correlation: the moving of Sun's path from south to north in the passage from winter to spring and summer.

### *Tracking Sunrise and Sunset Times*

The students recorded the sunrise and sunset times on each of the days they performed the three previous activities, and they plotted two graphs: one showing the sunrise and sunset times and one showing the number of daylight hours each day. Subsequently, they were asked a question that was supposed to summarize and connect all their observations: Is there some correlation between the number of daylight hours and the temperatures, the Sun's shadows, and the Sun's path in sky? Their answers showed that they understood the correlation between the different measurements they made, although they expressed these in different ways:

- Because the daylight hours grow from winter to summer, and the angle of the Sun's path moves from south to north, the temperatures get higher in the passage from winter to summer. These two phenomena exert an influence because we get more daylight hours and Sun's angle is more perpendicular, so temperatures get higher as winter gives way to summer (four students).
- As daylight hours increase temperatures get higher (three students).
- As the daylight hours increase temperatures get higher. Furthermore, the Sun's path moves north and the Sun's shadow becomes shorter (two students).
- As the Sun's path moves to a more northern position, the Sun's shadow becomes shorter at noon, daylight hours increase, and temperatures get higher (two students).
- Temperatures get higher in the transition from winter to summer because daylight hours increase and the Sun's path in the sky (the angle) moves from south to north (two students).
- The day becomes longer and the temperatures get higher. The Sun's shadows get shorter and the Sun's path moves to the north (one student).
- When the day becomes longer the temperatures get higher, the Sun's shadows shorten, and the Sun's path becomes nearer to the top of the dome, the center (one student).
- The day becomes longer so temperatures get higher. The number of daylight hours increases as the Sun's path moves to the north, so the Sun's shadow gets shorter (one student).
- As the day becomes longer temperatures get higher, the Sun's shadows get shorter, and this happens when we pass from winter to summer (one student).
- The correlation is that, as the Sun's shadows get shorter, temperatures get higher. There is also a connection between the temperature and the Sun's path: as the Sun moves to the north temperatures get higher and this is because of the angle of the Sun rays relative to the Earth, so when the angle widens the temperature rises also (one student).

### *The Angle of the Sun's Light Rays Relative to the Ground at Different Earth Positions*

In the last activity students were presented with two different pictures of models. One picture had the rotational axis of the Earth perpendicular to the plane of its path around the Sun, and the other had the rotational axis of the Earth tilted at an angle of  $23.5^\circ$ . This activity was intended to summarize all that the students had done so far, and it was performed in small groups in class; all groups were asked to write answers to a long series of questions. For example, in the perpendicular rotational axis model, they were asked to look at the three "persons" appearing in the picture and at the Sun's rays and to answer to the following questions: Which person sees the Sun's rays perpendicularly, exactly above his/her head? Which person sees the Sun's rays diagonally, shining on him/her from above? Which person sees the Sun shining horizontally, from his/her side, in parallel with the horizon? The students were asked to identify the size of the surface on Earth illuminated by the Sun's rays, and were asked the following questions: Are all the surfaces the same size? Where do the Sun's rays illuminate a smaller (and a larger) surface? Will all the

surfaces get hot equally? What part of latitude 30°N (and also 60°N, 30°S, and 60°S) is illuminated by the Sun (less or more than a half/exactly half)? Will the daylight hours be the same as the night hours at these latitudes? Does this model explain the results of your sunrise and sunset time measurements for several weeks? They were asked similar questions for the tilted rotational axis model.

All groups answered correctly the questions they were asked during the activity, particularly those that aimed at leading them to the conclusion that the reason for the change of seasons is the tilt of the rotational Earth axis relative to its path around the Sun, in contradiction to the widespread misconception that seasonal changes are due to the change in the distance between the Earth and the Sun.

*Posttest Results*

The posttest questionnaire (the same as the pretest questionnaire) was presented to the experimental class and to the control groups on their examination day; that is, several weeks after finishing the course, and about 6 weeks after the experimental class performed the last activity. Figure 7 shows the extent of success of the different groups in answering the whole questionnaire, and the questions about phenomena related to seasonal changes.

In the whole posttest questionnaire, we found a statistically significant improvement in all the groups with the largest effect size for the experimental class, as shown in Table 4 and for the seasons' questions we found a statistically significant difference only for the experimental class, as shown in Table 5. The significant improvement of the control groups in the whole questionnaire can be explained as follows: (a) their instructors were very experienced lecturers covering most topics based on well-structured lectures with a descriptive (phenomenological) rather than conceptual approach to astronomy; and (b) the questionnaire comprised several nonconceptual questions that required only factual recall.

We found some inconsistency in the posttest answers of several students from the experimental class:

1. Three students answered that the Sun is directly above us at noon every day, despite the fact that they answered correctly all of the other questions related to seasonal changes.

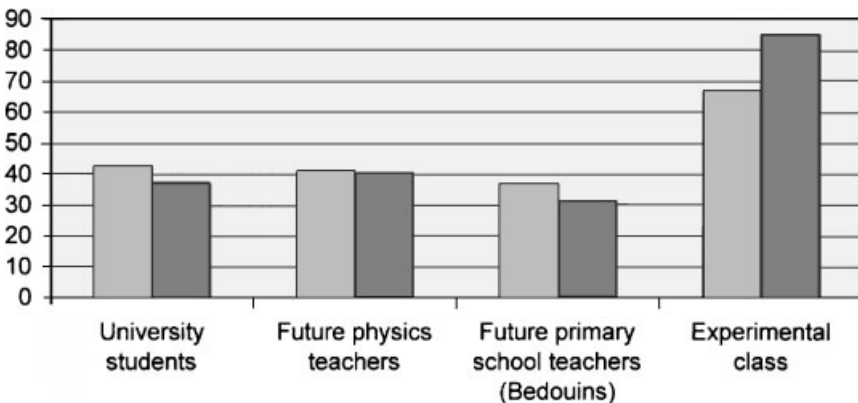


Figure 7. The extent of success (in percent) of the different groups in the posttest. Lighter bars: whole questionnaire; darker bars: seasons questions.

Table 4

*Comparison of the total success in the whole questionnaire (pre- and posttest) for all the groups*

	Pretest Total Success (Mean)	Posttest Total Success (Mean)	<i>t</i>	<i>p</i> -value	Cohen's effect size ( <i>d</i> )
University students	35.1	42.5	2.003	0.025	0.370
Future physics teachers	27.2	40.9	2.222	0.023	0.921
Future primary school teachers (Bedouins)	21.8	36.8	4.607	<0.001	1.165
Experimental class	24.8	67.0	10.19	<0.001	4.083

2. Six students answered that the main reason that it is hotter in summer than in winter is that the Earth's rotational axis flips back and forth as the Earth moves around the Sun; two of them answered that if the Earth's orbit were a perfect circle we would experience seasons in a more noticeable way. They answered correctly all the other questions related to seasonal changes.
3. Three students answered that if the Earth's orbit were a perfect circle we would no longer experience a difference between the seasons, yet they answered correctly all the other questions related to seasonal changes.

### Discussion and Educational Implications

Understanding the solar system involves a number of related conceptual areas that are clearly of importance in relation to student's existing frameworks and are difficult to explain because they do not match their daily observations. They include a perception of spatial aspects of the Earth, a conception of day and night, of seasonal change, etc., which include compound movements of the Moon, the Sun, and the stars. In this study we can see clearly that many students were not post-Copernican in their notions of planet Earth in space and they held alternative notions to the accepted scientific concept, in various basic astronomy subjects.

The findings of this study support the constructivist approach in teaching, in which students are confronted with their alternative conceptions in a conceptually centered learning environment that actively engages them. Although both the experimental class and the control groups improved their basic astronomy concepts in a statistically significant way, the experimental class made the most impressive improvement of all. Moreover, regarding the subjects relevant to this study (seasonal changes), only the experimental class showed a statistically significant improvement.

There remains a question that requires further research: To what extent are students' conceptions consistent and stable? As stated earlier, we found several cases in the experimental class, both in students' answers on the posttest and in the interviews, showing that we need a more

Table 5

*Comparison of the success in the questions dealing with seasons (pre- and posttest) for all the groups*

	Pretest Success (Mean)	Posttest Success (Mean)	<i>t</i>	<i>p</i> -value	Cohen's effect size ( <i>d</i> )
University students	36.3	37.1	0.167	0.43	0.04
Future physics teachers	27.1	40.5	1.712	0.06	0.725
Future primary school teachers (Bedouins)	25.0	31.2	0.951	0.18	0.346
Experimental class	27.8	85.1	14.29	<0.001	4.152

in-depth study of the consistency and stability of students' conceptions, even after they have been taught by a constructivist approach.

Several researchers have found that students' answers are inconsistent, and especially context-dependent (Finegold & Gorsky, 1991; Halloun & Hestenes, 1985; Savinainen & Viiri, 2003). In a study dealing with students' conceptual change process while learning about force and movement, Tao and Gunstone (1999) found that most students were unsure in their answers to the posttest, using their alternative conceptions and the accepted scientific concept in different contexts, showing that their conceptual change was context-dependent and unstable. Steinberg and Sabella (1997) claimed that different contexts and presentations could trigger different responses from a given student, even if the underlying physics is identical. Bao and Redish (2001) argued that strong context dependence in student responses is very common, especially when students are just beginning to learn new material. Students are not sure of the conditions under which the rules they have learned apply, and they tend to use the rules either too broadly or too narrowly.

This context dependence raises the question of students' conceptual change stability. Several researchers have stated that the conceptual change process might be difficult and progressive (Driver & Bell, 1986; Smith, Carey, & Wiser, 1997; Vosniadou, 1991). We conclude that, although the learning of a new subject such as astronomy in a constructivist way may encourage students to rethink the accuracy of their alternative conceptions, they need further experiences to apply correctly the new concepts learned and reinforce their understanding.

For the students participating in this study, the introductory astronomy course was the first time they learned some basic astronomy concepts. The experimental instructional activities applied in the experimental class were designed to deal with students' alternative conceptions and to help them understand the accepted scientific concept. In parallel, they showed future teachers some alternative (constructivist) ways of teaching. Good teachers need to possess not only a detailed and subtle understanding of the subject matter, but also in-depth knowledge of how best to present it in the classroom setting, currently called "pedagogic content knowledge" (Parker & Heywood, 1998; Shulman, 1987). This means that teachers need to be in control of their own learning and develop an understanding of how they might learn effectively (metacognition). When implementing reform in science curriculum as recommended by the Tomorrow 98 (1992) report, the change has to include not only the subjects being taught but also the way they are taught.

## Appendix

*Questionnaire: The Earth and the Universe* (✓ indicates the correct answer)

1. As seen from your current location, when will an upright flagpole cast no shadow because the Sun is directly above the flagpole?
  - A. Every day at noon.
  - B. Only on the first day of summer.
  - C. Only on the first day of winter.
  - D. On both the first days of spring and fall.
  - E. Never from your current location. ✓
2. In order to have a total solar eclipse, the Moon must be at what phase?
  - A. Full.
  - B. New. ✓
  - C. First quarter.
  - D. Last quarter.
  - E. At no particular phase.

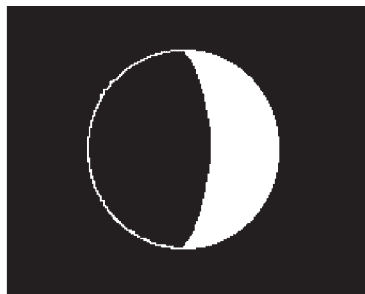


3. Imagine that you are building a scale model of the Earth and the Moon. You are going to use a basketball with a diameter of 30 cm to represent the Earth and a tennis ball with a diameter of 7.5 cm to represent the Moon. To maintain the proper distance scale, about how far from the surface of the basketball should the tennis ball be placed?
- A. 10 cm.                      B. 15 cm.                      C. 90 cm.  
D. 9 m. ✓                      E. 90 m.
4. What causes night and day?
- A. The Earth spins on its axis. ✓  
B. The Earth moves around the Sun.  
C. Clouds block out the Sun's light.  
D. The Earth moves into and out of the Sun's shadow.  
E. The Sun goes around the Earth.
5. The diagrams here show how the Moon appeared one night, and then how it appeared a few nights later. What do you think best describes the reason for the change in the Moon's appearance?

One night



Few nights later



- A. The Moon moves into the Earth's shadow.  
B. The Moon moves into the Sun's shadow.  
C. The Moon is black on one side, white on the other, and rotates.  
D. The Moon moves around the Earth. ✓
6. The main reason that it is hotter in the summer than in winter is that
- A. The Earth is closer to the Sun in summer.  
B. The Earth is farther from the Sun in summer.  
C. The Earth's rotational axis flips back and forth as the Earth moves around the Sun.  
D. The Earth's axis points to the same direction relative to the stars, which is tilted relative to the plane of its orbit. ✓  
E. The Sun gives off more energy in the summer than in the winter.
7. Where does the Sun's energy come from?
- A. The combining of light elements into heavier elements. ✓  
B. The breaking apart of heavy elements into lighter ones.  
C. The glow from molten rocks.  
D. Heat left over from the Big Bang.





20. With your arm held straight, your thumb is just wide enough to cover up the Sun. If you were on Saturn, which is 10 times farther from the Sun than the Earth, what object could you use to just cover up the Sun?
- A. Your wrist.                      B. Your thumb.                      C. A pencil.  
 D. A toothpick. ✓                      E. A hair.
21. Global warming is thought to be caused by the
- A. Destruction of the ozone layer.  
 B. Trapping of heat by nitrogen.  
 C. Addition of carbon dioxide. ✓

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