Investigating teacher understanding of observational astronomy: the sun

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In this paper I describe an investigation of teacher understanding of observational astronomy with particular emphasis on sun-related topics. Although teachers can generally complete simple data extrapolation tasks, they have serious difficulty generalizing what they have learned and observed to an accurate physical model. Insights gained from this research directed the revision of curriculum in order to better address teacher difficulties.

I. BACKGROUND

Research has shown that certain conceptual difficulties persist, even after standard, lecture-based instruction in introductory and advanced physics courses. Often neither a deep conceptual understanding nor a strong foundation for reasoning ability follows from this type of instruction. On the basis of these findings, we can conclude that "teaching by telling" is not the most effective instructional strategy for the majority of student learners.[1]

In order to promote the improvement of student understanding in physics, the Physics Education Group (PEG) conducts an iterative process of research, curriculum development, and instruction. As a part of their research, the group analyzes student responses to pretests (taken before instruction on a particular topic) and post-tests (taken after instruction on that topic) to identify widespread conceptual difficulties; they conduct interviews to probe the depth and breadth of those conceptual difficulties; and they make further observations in the classroom. The group then develops a carefully-sequenced curriculum: experiments and exercises which elicit, confront, and resolve known conceptual difficulties and deepen understanding about a relevant topic. The two primary texts that the PEG has developed as a part of this process are *Physics by Inquiry (PbI)*, for use primarily in the professional development of K-12 physical science teachers, and *Tutorials in Introductory Physics*, a supplementary text to the introductory physics course sequence at the college or university level. The use of *PbI* materials in the classroom is via a process called "guided inquiry."[2] There are no lecture-based curricula; students work in small groups and are led through "check-outs" with instructors – an opportunity for students to display their understanding of what they have learned by answering questions and a chance to be led through areas of difficulty via the inquiry process – at the end of specified sections in the curriculum.

An integral part of this effort are special courses for the preparation of both pre-service and in-service teachers of science. Inquiry-based learning is especially important for teachers, for whom it affords an opportunity to study the subject matter in depth and provides a context for learning that is consistent with the way in which teachers are expected to teach. These special courses emphasize the scientific process and promote the development of strong reasoning skills. They facilitate depth of understanding as well as an appreciation for conceptual difficulties that their students may encounter.[3]

The particular investigation described in this paper was conducted during the National Science Foundation's Summer Institute in Physics and Physical Sciences for in-service K-12 teachers at the University of Washington. As a part of the course, teachers work through curriculum from *Physics by Inquiry* for six weeks during the summer. Classes meet from 9 a.m. to 3:30 p.m., four days a week, with a three-hour morning curriculum session which runs for the entire duration of the course (six weeks - 66 hours of instruction total) and two, three-week afternoon curriculum sessions which meet for two-and-a-half hours each day (27.5 hours of instruction total). A mid-term and a final exam are given during the course. Teachers demonstrate a variety of mathematical and science backgrounds.

II. OVERVIEW OF ASTRONOMY BY SIGHT-SUN CURRICULUM AND MOTIVATION FOR INVESTIGATION

The Astronomy by Sight-Sun (AbS-Sun) curriculum, like all *Physics by Inquiry* curriculum, places a strong emphasis on the scientific process and on scientific reasoning skills. It stresses operational definitions - statements which define the operations, or steps, one must complete in order to classify or define a particular item. For example, one acceptable operational definition for "vertical" is as follows: the direction defined by a string that has been hung from a nail in the wall and has a weighted object attached to it. As students work through the AbS-Sun module, they learn the importance of making predictions and ensuing observations which will either confirm or disaffirm their predictions. Students are asked to resolve any differences between their predictions and their observations and then, based on the observations they actually make, to develop a physical model for the earth and sun. The model which arises from the AbS-Sun curriculum is one that describes a round earth and far-away sun. Both the geocentric (earth-centered) and the heliocentric (sun-centered) models are examined, and, on the basis of observations made, students conclude that neither is more or less plausible.

The primary means of observation in the AbS-Sun curriculum is a shadow plot (see Fig. 1, pg. 2). Shadow plots are made by recording the pattern made by the tip of a shadow of a vertical object throughout a single day. Students make shadow plots throughout the curriculum and are provided with

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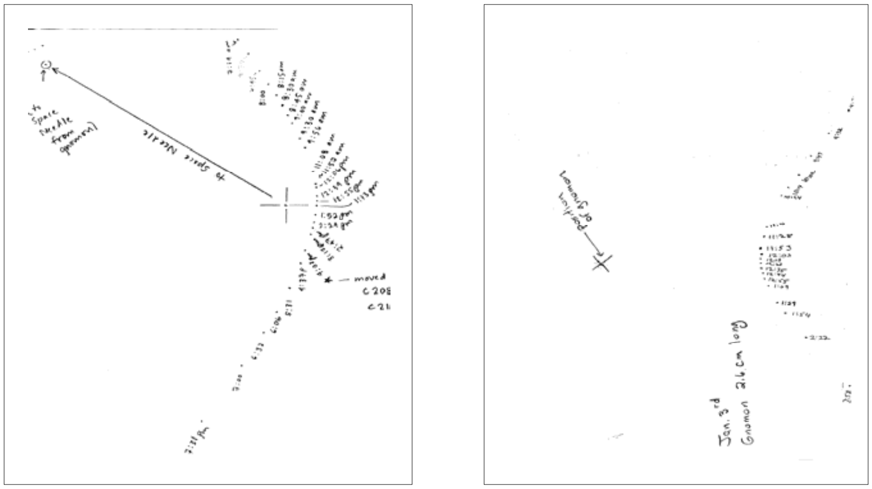
[1] L.C. McDermott, "Oersted Medal Lecture 2001: "Physics Education Research – The Key to Student Learning*,"* Am. J. Phys. **69** (11), 1127-1137 (2001).

[2] Guided inquiry is also an important part of the *Tutorials* but less so than for *PbI*.

[3] L.C. McDermott, "A perspective on teacher preparation in physics and other sciences: The need for special science courses for teachers," Am. J. Phys. **58** (8), 734-742 (1990).



(a) (b)

Fig.1 Shadow plots used in the AbS-Sun curriculum. Fig. 1(a) illustrates a shadow plot made June 24th with a gnomon 2.9 cm tall. Fig 1(b) illustrates a shadow plot made January 3rd using a gnomon 2.6 cm tall. (Note: due north points to the direct right of the page.)

shadow plots made during different times of the year.

This year (2005), 38 teachers in the Summer Institute participated in the AbS-Sun curriculum. Twenty of these were high school teachers and worked through the module during the first three-week session of the Institute. Fifty percent of these had previously taught astronomy, and 20% had specifically taught sun-related topics. Eighteen participants worked through the curriculum during the second three-week session. This population was primarily composed of elementary and middle school teachers. About 60% had formerly taught astronomy and about 35% sun-related topics.

Before instruction, teachers were asked to complete a module pretest which asked them to predict the shape traced out by the tip of the shadow of a vertical object (also referred to as a *gnomon*) throughout the course of both one day in January and one day in June (see Appendix A). In addition, the pretest asked them to explain their reasoning. Fig. 1 shows two actual shadow plots made in January and June. As can be inferred from the plots, the earliest a.m. shadow points south of west in June and north of west in January; the mid-day shadow always points due north; and the latest p.m. shadow points south of east in June and north of east in January. Only 10% of the first group (session one – high school teachers) correctly predicted both shadow plots, and none of the second group (session two – elementary and middle school teachers) gave an accurate response. Of all of those who had previously taught sun-related topics, only 10% responded correctly. We can see, therefore, that those who teach a subject do not necessarily possess a deep understanding of the subject matter. We wanted to deepen our understanding of the extent and nature of teacher difficulties and to determine their pervasiveness.

III. OVERVIEW OF THE INVESTIGATION

Based on the analysis of post-tests given after both sessions of the afternoon AbS-Sun curriculum, we were able to determine that teachers, in general, do not have difficulty gathering important data from shadow plots. For example, teachers are led through a series of exercises in the curriculum that allow them to extrapolate data from shadow plots. They learn how to determine the shortest shadow of the day and the altitude (angle which the sun makes with horizontal ground) of the sun at any given time that is represented by a point on the shadow plot. In addition, they are taught how to determine the season on the basis of the general shape of the shadow plot for a day, etc.

Four post-test questions (see Appendix B), two given after the first session of the curriculum and two given after the second, reveal that more than 95% of the teachers have no difficulty with these operations. More detailed results are presented in Table I.

Table I. Results from post-tests which illustrate tasks performed well by teachers

	High school teachers, Session 1 (N=20)	Elementary/Middle school teachers, Session 2 (N=18)	Total (N=38)
Able to:			
determine shortest shadow of the day	95%	100%	97%
determine altitude of sun on basis of shadow plot point	100%	100%	100%
determine season on basis of general shadow plot curve	…	100%	…

However, from our analysis, we have also seen that a significant portion of the participants in the Summer Institute have trouble generalizing what they have learned and observed in the AbS-Sun module to an accurate physical model. In particular, teachers struggle what we will hereafter call the "parallel-light/far-sun" concept. Because of the great distance between the earth and sun, incoming light from a point on the sun is essentially parallel by the time it reaches the earth. Teacher difficulties with this idea are further elaborated in the following several sections.

IV. ANALYSIS OF PRETESTS FROM PREVIOUS SUMMER INSTITUTES

The AbS-Sun curriculum has been used for several years as a part of the Summer Institute (although it has not often been used twice in one summer). In preparation for the analysis of the 2005 Summer Institute data, and in order to determine if any revisions to former pretest questions were needed, an examination of data from previous Summer Institutes was conducted. Two pretests are of particular relevance to this study, the "two poles" pretest and the "two students" pretest.

a. Test on two poles' shadow comparison

The "two poles" pretests analyzed were administered over three different Summer Institutes and totaled 98 respondents. The pretest question (Appendix C) asked teachers to compare the shadow lengths cast by two identical, vertical poles, one on the top of a building and one on the ground below [see Fig. 2(a)]. No diagram was provided for participants; they were asked to draw a diagram (see Appendix B for copy of actual pre-test). No instruction regarding the parallel-light/far-sun idea had been given at the time of this pretest.

A correct response with complete reasoning required that teachers state explicitly that incoming light from the sun is parallel (or essentially parallel) because the sun is very far away and, therefore, that teachers conclude that the altitude of the sun would be the same for both poles, resulting in shadows of identical length.

1. Teacher responses

Even though 60% gave correct responses which indicated that the shadow lengths of both poles were equal, only ten percent justified their answer completely (see Table II, pg. 4).

Ten percent gave what will henceforth be called the "limiting argument" – they claimed that the distance between the two poles was negligible in comparison to the distance from the poles to the sun. Although this limiting argument is correct in some senses, it often led to the additional statement that perhaps, if the poles were further apart (say, one mile), one might be able to notice a difference in the altitude of the sun and thence a difference in the shadow lengths of the poles. This extension of the "limiting argument" is incorrect, as light from a point on the sun is parallel *by the time it reaches earth*; in other words, no distance on the earth can neutralize this effect.

Twenty percent assumed the sun was close [see Fig. 2(b)]. Most students (as in the figure) drew a diagram of the sun, emitting two non-parallel rays, one which passed from a point on the sun to the top of the pole on the roof and extended to the ground and one which passed from the same point on the sun through the top of the pole on the ground. Therefore, the altitude of the sun could not be the same for both poles, and their shadow lengths were different.

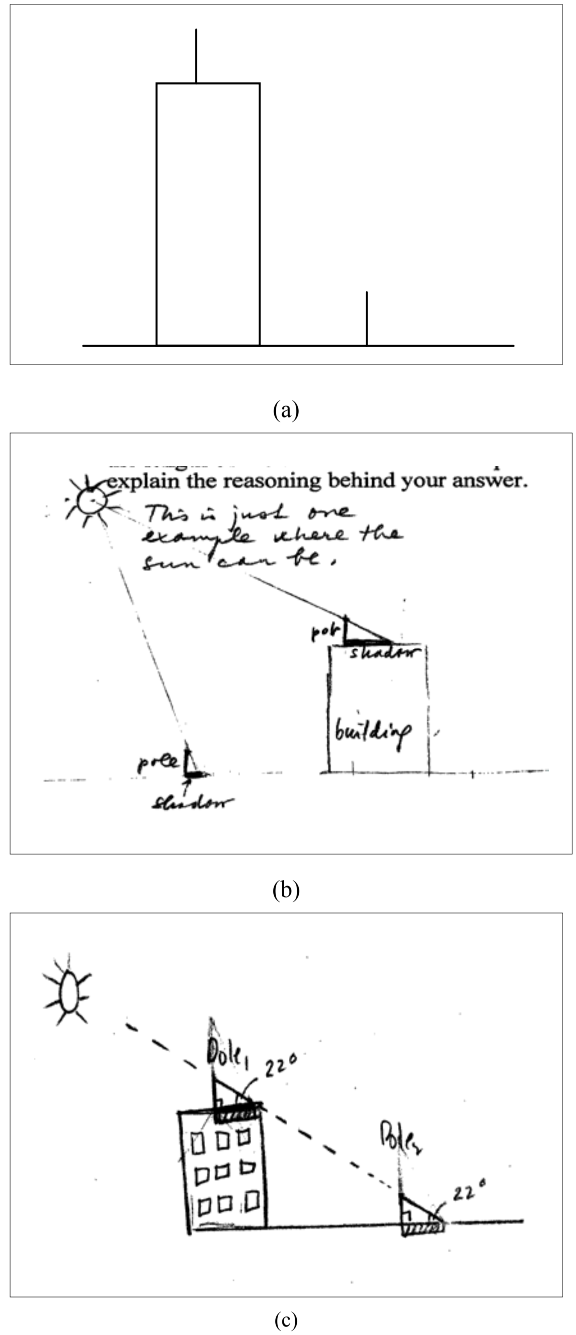


Fig. 2. (a) Diagram which illustrates two poles pretest. (b) An example of the incorrect "close-sun" response to the two poles question. (c) An example of the ambiguous "single ray" response to the two poles question.

There was some difficulty categorizing the responses, specifically due to diagrams which accompanied 20% of the answers. Several teachers drew a single ray which emanated from a close sun and passed through both poles, creating equal shadow lengths [see Fig. 2(c)]. This created some confusion in

Table II. Results from analysis of previous years' two poles pretest data.

	Pretest (N=98)
Correct (shadow lengths same)	60%
Correct with complete reasoning	10%
Limiting argument'	10%
Most common incorrect:	
Close sun	20%

analysis – did students believe that the sun was close and that another ray which originated at the same point on the sun would not be parallel? Did they support the limiting argument? In order to resolve this difficulty in interpretation, a revision to the pretest was suggested.

2. Revision to the two poles pretest

In order that teachers' diagrams would better expose their reasoning, we added an additional pole at ground level to the pretest, identical to the first two, ten meters farther from the building than the original (Appendix D). There were now three poles whose shadows we asked teachers to compare: in part (a) of the revised question, teachers were to compare the shadow of the pole on the top of the building and the shadow of the original ground-level pole; in part (b), they were to compare the shadows of the two ground-level poles. Teachers would find it necessary to draw diagrams which would reveal whether or not they visualized light from the sun as parallel. A correct response to both parts of this revised question required essentially the same reasoning as discussed above for the previous version. This pretest was given during the 2005 Summer Institute. The results will be discussed in the next section.

b. Test on two students 500 miles apart

The "two students" pretests analyzed were given over the period of three years and included 84 participants in the Summer Institute. Some prior instruction had been given about the far sun/parallel-ray concept. The pretest question (Appendix E) presents the following situation: a student finds that the sun is directly overhead. The pretest then asks whether, at the same instant, another student who is 500 miles due north of the first will also see the sun directly overhead. It follows with another question: if the second student will *not* see the sun directly overhead at that instant, will there be another time when he or she will?

1. Teacher responses: first question

A fully-justified, correct response to the first question necessitated that students take into consideration both the curvature of the earth and the far distance to the sun (and therefore that the sun's incoming light will be parallel). The diagram in Fig. 3 illustrates this response. Student 2 will not see the sun directly overhead at the same instant as student 1.

Although about 60% of the participants were able to conclude that both students will not simultaneously see the sun

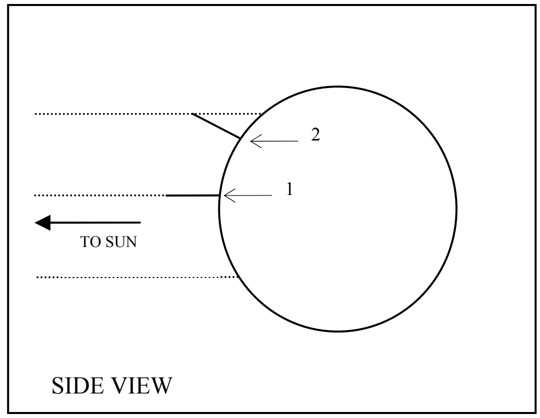


Fig. 3. Illustration of correct response to two students problem.

directly overhead, only about 25% supported their answer with complete reasoning (see Table III). About 20% drew a diagram of a curved earth or else mentioned the curvature of the earth in their response but displayed an obvious misunderstanding of the parallel-light/far-sun concept; they drew diagrams of the sun close to the earth.

About 15% applied the limiting argument; their responses indicated that the sun is so far away from the earth that the 500 miles between the two students will make no difference in the altitude of the sun at the two locations. Again, we must ask these teachers: at what distance does the limiting argument fail?

2. Teacher responses: second question

Much confusion arose due to the wording of question 2; it seemed to ask whether student 2 would *ever* see the sun directly overhead rather than whether student 2 would see the sun directly overhead at any time during the *same day* as student 1.

The analysis of this question was difficult. Several complications arose due to the words "directly overhead;" teachers often commented that the sun would never be directly overhead or made statements about locations on the earth at which the sun could possibly be overhead rather than answering the question. About 15% believed that whether student 2 would see the sun directly overhead depended on his or her latitudinal position.

With the intent of the question in mind, approximately 10% of respondents gave a correct answer provided complete reasoning (not discussed here); they asserted that the sun would never be directly overhead for student 2 and justified their answer by referring to local noon.

Table III. Results from analysis of previous years' two students pretest data.

	Pretest (N=98)
Correct (not directly overhead simultaneously)	60%
Correct with complete reasoning	25%
Limiting argument'	15%
Most common incorrect:	
Close sun	20%

3. Revisions to the two students pretest

Because of the considerable miscommunication on behalf of the question, several revisions were made. The words “directly overhead” were emitted, and the former situation was replaced by one in which two students, 500 miles apart along a north-south line (the first placed in the teachers’ current location) concurrently make a shadow plot. The teachers are then asked to compare, separately, the direction and the length of the shadows made by the respective students at local noon (same time for both students). This revised version of the pretest (Appendix G) was given during the 2005 Summer Institute. The results will be discussed in detail below.

V. ANALYSIS OF 2005 SUMMER INSTITUTE PRETESTS

a. Three poles pretest (2005)

The revised three poles pretest (discussed in detail in section IV, part a, above) was administered to both sessions of the 2005 Summer Institute AbS-Sun curriculum (N = 38). Because parts (a) and (b) require essentially the same reasoning, only part (a) will be discussed here. The results are shown in Table IV. Here, also, no prior instruction covering the parallel-light/far-sun idea had taken place.

i. Teacher responses

Approximately 50% of the participants correctly answered that the shadow lengths of the roof- and ground-level poles are the same; however, only about 10% provided sufficient reasoning to support their response. About 30% gave the close-sun argument, and 10% gave the limiting argument. An additional 15% gave an either/or response: they drew a diagram of a close sun with non-parallel rays emanating from a point and different shadow lengths for the two poles but then stated that, since the sun is so far away relative to the distance between the two gnomon, the difference in shadow length may or may not be significant. They strongly supported neither the close-sun nor the limiting argument case.

We see, from these results and from the data analysis from previous years, that the misconception that the sun is close to the earth and that rays which emanate from a point on the sun are not parallel by the time they reach earth is widespread.

None of the participants in the first session (2005) drew diagrams where a single ray emanating from the sun passed through both the roof- and ground-level poles, and only about ten percent did so in the second session. Of those, however, we were able to deduce, from the diagram accompanying their

Table IV. Results from revised three poles pretest (2005)

	Session 1 (N=20)	Session 2 (N=18)	Total (N=38)
Correct (shadow lengths same)	50%	50%	50%
Correct with complete reasoning	10%	5%	10%
"Limiting argument"	15-40%	5-10%	10-25%
Most common incorrect:			
Close sun	25-50%	40-45%	30-50%

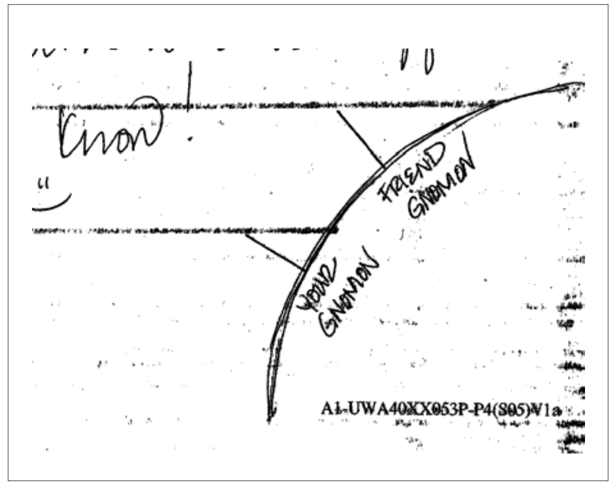


Fig. 4. Correct student response to the revised two students pretest question

responses for part (b), whether they thought the sun was close or whether they imagined the sun far away with incoming parallel light.

ii. Effect of revision on data analysis

Referring to **Tables II and IV**, we see that there is a more prevalent difficulty with the parallel-light/far-sun concept than revealed by the former two poles pretest question. The percentage of ‘correct and complete’ responses was consistent, as was the limiting argument. However, with the revised pretest, an additional 10% of respondents provided a diagram and reasoning that supported the “close-sun” case, and 10% fewer offered a correct response. We can conclude that the revision was effective. We can more readily characterize teacher responses as correct/incorrect, and we are able to deduce, by employing diagrams from both parts (a) and (b), whether or not they visualize light from the sun as parallel.

b. The parallel-light/far-sun idea, a closer look: two students pretest (2005)

The revised version of this pretest was given to both AbS-Sun sessions of the 2005 Summer Institute (N=33). Again, this pretest was administered after some instruction regarding the parallel-light/far-sun idea. The responses to the question which compared the lengths of the shadows at local noon for both students are discussed here.

A completely justified, correct response required the same reasoning as before, but the revised question asks for teachers to compare the shadow lengths at local noon for the two students (rather than whether both instantaneously experienced the sun directly overhead). Fig. 4 illustrates a correct response. In addition to a correct diagram, teachers must also accurately explain the far-sun/parallel-light concept and account for the curvature of the earth in order for their response to be complete.

Table V. Results from revised two students pretest (2005)

	Session 1 (N=20)	Session 2 (N=18)	Total (N=38)
Correct (shadow lengths different)	75%	55%	65%
Correct with complete reasoning	20%	20%	20%
"Limiting argument"	15%	15%	15%
Incorrect response			
Close sun	25%	15%	20%

i. Teacher responses

Even though about 65% could state that the local noon shadow lengths would not be the same, only about 20% were able to completely justify their responses (see Table V). This *is* an improvement from the three poles pretest (see Table IV), but it is not significantly better. Twenty percent still make a case for a close sun (improved from 30% in the three poles pretest), and 15% give the limiting argument. So we see that, even after instruction, there still remains a significant misunderstanding about the placement of the sun relative to the earth and the implications of this representation.

Although only 20% gave the close-sun argument, 35% of the responses included diagrams in which a close sun radiated non-parallel rays from a point. This is telling: the diagrams teachers draw denote their own mental representation of the relative locations of the earth and sun. Although they can explain why they think the shadows should be different, their diagrams are inconsistent with their responses and suggestive of an even more significant conceptual difficulty than is implied by the pretest responses.

VI. ANALYSIS OF 2005 SUMMER INSTITUTE POST-TESTS

A post-test was given following the first session of AbS-Sun (N=20) which essentially asked teachers the same question that the three poles pretest did. The post-test question (Appendix G) presented the following situation [see Fig. 5 for illustration (not given to teachers) of question]: three students make shadow plots on a winter day in Seattle. Student A stands at the top of a tall cliff that runs east-to-west; student B stands directly below on the ground; and student C stands thirty feet farther from the cliff, due south of student B. The question asked teachers to compare the shadow plots made that day by: (a) students A and B, and (b) students B and C. For the purposes of this investigation, only part (a) will be discussed here.

A completely justified, correct answer, here, also, requires the same reasoning as the three poles pretest question. Teachers must display a robust understanding of the parallel-ray/far-sun concept and must not draw a diagram which is in conflict with this idea.

a. Background

Prior to administration of the post-test, teachers have received instruction which supports the parallel-light/far-sun

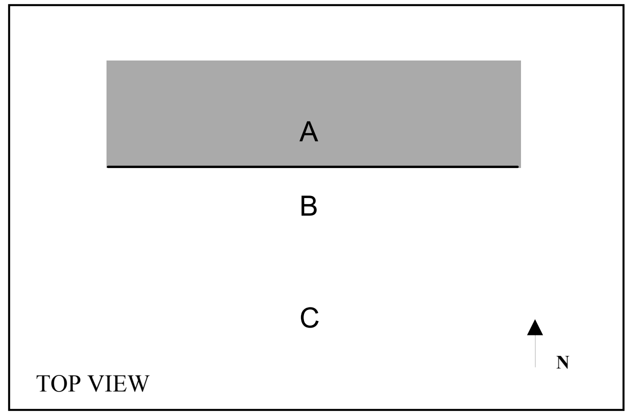


Fig. 5. Diagram which illustrates cliff post-test question.

Table VI. Results from cliff post-test (2005)

	Pretest, Session 1 (N=20)	Post-test, Session 1 (N=20)
Correct (shadow plots same)	45%	95%
Correct with complete reasoning	10%	20-40%
"Limiting argument"	10-35%	45%
Incorrect response		
Close sun	25-50%	5%

idea. Teachers have been asked to recognize the error in a close sun drawing and to explain any discrepancies between the drawing and observations (either made by or given to them) from the module. They have calculated the circumference of the earth, and, in order to do so, have had no choice but to assume that incoming light from the sun is parallel over a distance of at least 500 miles.

In one of the final sections of the module used in the first session of the 2005 Summer Institute, teachers are asked to synthesize the ideas they have accumulated in the module to form a physical model which accurately represents the sun and earth. However, in this section, there was no reinforcement of the parallel-light/far-sun idea. In fact, the simplifying representations teachers used to visualize the model they developed included a light bulb ‘sun’ held a few feet from a stationary- or rotating-head ‘earth’ – this simple “model” may have reinforced any lingering misconceptions about the sun’s proximity to the earth.

b. Teacher responses

Ninety-five percent were able to answer the post-test question correctly, as compared to the 45% which correctly answered a similar question on the pretest (see Table VI). Between 20 and 40% answered the post-test question correctly and provided complete reasoning – the range of values arises due to the following. Twenty percent of respondents explicitly stated that incoming light from the sun is parallel; an additional 20% stated that the altitude of the sun for both students was the same due to the great distance to the sun. This additional 20% was correct, but their response hints at the limiting argument. There was no way to categorize their thinking from their responses and/or diagrams.

Forty-five percent gave the limiting argument. Only 5% maintain that the sun is close; however, 30% of the participants drew diagrams with the sun close to earth, and two-thirds of these showed non-parallel rays emanating from a point on the sun.

We can conclude that, even after instruction, there are still underlying misconceptions about the closeness of the sun to the earth. Though only 5% used their diagrams to support their reasoning, at least 20% still inaccurately represent their mental picture of the "physical model" with a close sun. Because of this vast misunderstanding/misrepresentation, a revision to the curriculum was initiated.

VII. REVISIONS TO SECTIONS SIX AND SEVEN OF THE CURRICULUM

a. Overview of Sections 6 and 7 – not revised

Before revisions were made, Section 6 (Appendix H) led teachers through a series of exercises that established a model which generally accounted for a handful of the observations they made during the course. In addition, it invited them to think about whether a rotating-earth/stationary-sun (called heliocentric in the module) or a stationary-earth/revolving-sun (geocentric) model is more credible. Teachers conclude that, according to what they have seen, neither is more plausible. In addition, an aid to thinking about sunrise, sunset, and local noon is established in terms of "clock times." In order to preserve a 24-hour day for this model, sunrise must occur at 6 a.m., local noon at 12 p.m., and sunset at 6 p.m. To visualize the models, teachers' eyes represent an observer on the earth (their heads) by either rotating in place with a light bulb 'sun' only feet from their heads (heliocentric) or by standing still with a light bulb 'sun' revolving around their heads (geocentric).

Sections 7 and 8 (Appendix H) prompted teachers to think about any inconsistencies that remained between the physical model developed in Section 6 and the observations they had made throughout the course. Teachers were further encouraged to think about how to resolve these discrepancies by making a single change to their models. The investigation was reasonably open-ended (when compared to the rest of the module), and teachers were expected to make adjustments until their models were as accurate as possible.

b. Revisions made to Sections 6 and 7

Due to the unresolved difficulties that were uncovered by analysis of the cliff post-test question from the first session and some lack of clarity achieved in check-outs from the former Sections 7 and 8, several revisions were made to Sections 6 and 7 (Appendix I) prior to their introduction in the second session. Diagrams showing a light bulb 'sun' close to a head (earth) were omitted. This was done in order to clear up any uncertainty about the way in which the physical model can be accurately represented based on the simple model we suggested as a means of visualization.

In addition, we asked students to think about their physical models in terms of a small observer on a large, round earth and to draw side- and top-view diagrams of the earth to illustrate the location of the observer from Section 6. For there to be consistency between Sections 6 and 7, and in particular, in order for the clock times discussed for sunrise, local noon, and sunset to be preserved, teachers are forced to again realize the parallel-light/far-sun concept. Here they also recognize that in order for the times to be preserved, the light must be parallel *over the entire surface of the earth*. Furthermore, students complete an added exercise in which they determine their location on earth based on the altitude of the sun from the shadow plots used in the course of particular days during the year. In doing so, they must again assume the parallel-light/far-sun argument.

c. Results

The revised Sections 6 and 7 were a part of the second session's AbS-Sun curriculum. Unfortunately, not all teacher groups were able to complete Sections 6 and/or 7 in the allotted time. Therefore, post-test results from the second session are not indicative of the effect of these revisions. Future post-testing, however, will be helpful in the analysis of their success.

VIII. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

a. Conclusions

Although teachers can perform well on tasks which require extrapolation of data from a shadow plot, they often have trouble generalizing what they have learned and observed to an accurate physical model and consistently describing that physical model both in words and with diagrams.

b. Suggestions for future research

1. Section 6 pretest

In recent years, there has not been a Section 6 pretest. It would be helpful to know the precise physical representations teachers/students have built for themselves while working through the module and the extent to which those representations are remnants of information/ideas brought into the course (rather than learned there). A pretest question for Section 6 should prompt teachers/students to both explain in words and to draw their representation for the sun and the earth.

2. Supplement for side- and top-view diagrams as well as physical model representations

As discussed above, the responses for several pre- and post-test questions brought to light a struggle with the relationship between a correct answer and an accurate diagrammatical representation of that answer. Many inconsistencies were noted between teachers' written response and the drawings that accompanied them.

In addition, teachers were asked to complete a pretest (Appendix J) which required that they make predictions about shadow lengths based on a side-view diagram of a light source

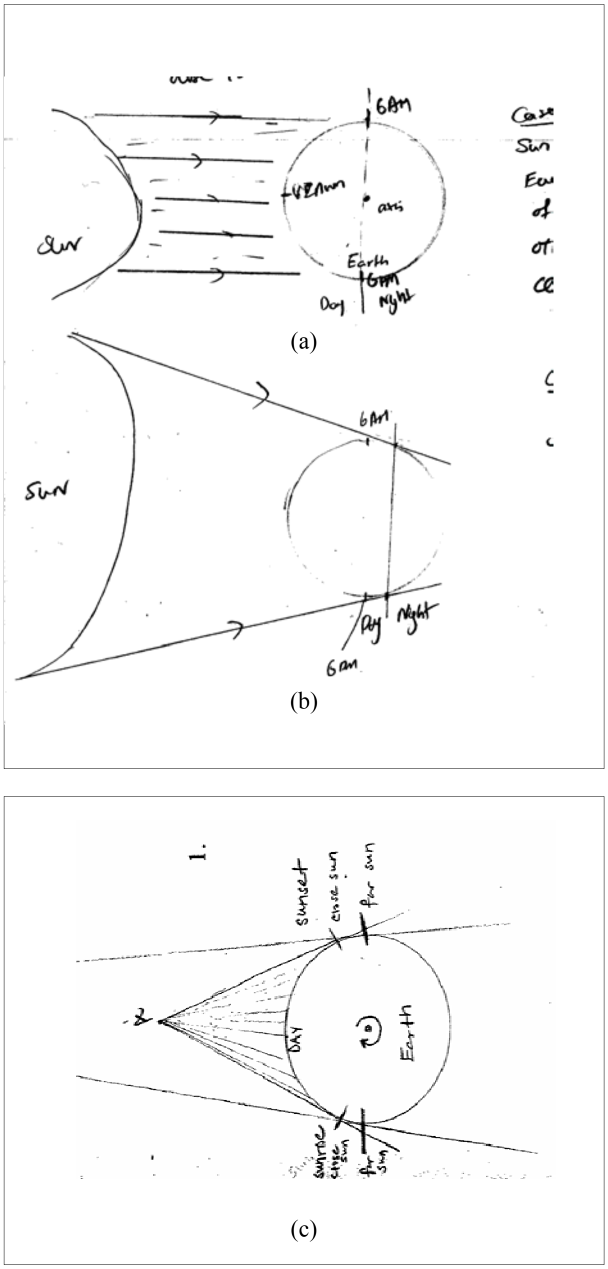


Fig. 6. Correct student responses to day-length post-test question. (a) Illustration of the far-sun representation. (b) Illustration of large, close-sun representation (extended point source). (c) Illustration of "point source" close-sun representation.

and nail. Some teachers had difficulty interpreting this side-view diagram; one teacher wrote, "This side view is very confusing!"

As a part of the new Section 7, a side- and top-view interpretation of the physical model (round earth, small observer) has been added. In order that teachers do not continue to struggle with interpreting these types of diagrams, and in order to address the inconsistency inherent in a seemingly-correct written response with an accompanying close-sun diagram, we have in mind a supplementary exercise on interpreting side- and top-view diagrams as well as some instruction regarding the accurate diagrammatical representation of the physical model.

3. Point source/extended point source resolution

An additional suggestion arises from the contention that the sun is a point source versus the claim that the sun is an extended point source. In actuality, the sun is not a point source but an extended point source (a "series" of point sources grouped together).

This dichotomy surfaces in the curriculum's definition of sunrise and sunset. The module defines sunrise as the moment at which *any part of* the sun appears over an observer's true horizon, and sunset is similarly defined as the point at which the *uppermost part of* the sun disappears over the true horizon. Here, the curriculum has taken into consideration the extended-point-source-nature of the sun, but for the rest of the curriculum, treats the sun as a point source to simplify matters. Observations in the classroom expose some teacher difficulty with this conflict – some teachers wanted to define sunrise or sunset as the instant at which the center of the sun comes over or goes beyond, respectively, the true horizon – but usually conceded after some discussion.

Moreover, one other post-test question (Appendix K) was given following the first session of AbS-Sun. It asked participants to compare the interval of time between sunrise and sunset for a physical model in which the sun was relatively close to earth and a physical model in which the sun was extremely far from earth. Teacher responses showed a great deal of confusion in terms of the point-source/extended-point-source idea. Several either treated the close sun as a large, extended point source (30%), in which case the close-sun model day length would be longer (see Fig. 6) than for a distant sun. Many considered the sun a point source (55%), in which case the day length for a close sun would be shorter than for a far sun (Fig. 6). Some gave both cases (5%).

It seems that an exercise/experiment or supplement needs to be added to the curriculum to resolve this discrepancy between what the curriculum implies and what teachers/students take away from it. The predicament lies in the placement of such an exercise. It is not especially relevant to any one current curriculum section but is an important underlying concept to walk away with.

4. Section 4 pretest revision

There currently exists a Section 4 pretest (Appendix L) that addressed the annual motion of the sun and shadow plots over the course of an entire year. It asks students to record any changes they have noticed in the daily motion of the sun over the course of the year and subsequently asks them to describe how the changes they listed would affect a shadow plot, if at all.

An analysis of the teacher responses convinced us that the question is too open-ended and that it asks teachers to make predictions which may not be resolved by the curriculum. For example, about 20% of the respondents (N=34) observed that the day length changes throughout the year. Many of these same students said that this observation would change the number of shadow-plot points on a graph. This, of course, depends on the interval at which one places points on the shadow plot (the plots the teachers have seen in the curriculum certainly do not have uniform intervals between shadow plot points). In addition, a number of those who believed the length of day would change throughout the year also added that its effect would be to lengthen the curve; shadow plot points that corresponded to earlier and later times would be plotted, and the effect of this would be to lengthen or shorten the imaginary curve which runs through the plotted points. Although the first idea is incomplete and the second invalid, neither are addressed in the curriculum. Therefore the pretest elicits ideas that are neither confronted nor resolved.

Rather than simply changing the pretest, perhaps adding an exercise or two in which teachers determine whether length of day *does or does not* affect the length or shape of a shadow plot would be useful. In addition, asking teachers, while working through curriculum, to think about how length of day affects the *number* of shadow plot points would force them to state the assumption they make in stating this is so – that points are plotted at equal time intervals each day throughout the year.

Only after these revisions could we add a pretest question which asks teachers to predict whether the shadow plot for a long day would be *longer than*, *shorter than*, or *equal in length to* a shadow plot from a shorter day. In addition, asking more direct questions about the effect of a particular change in daily motion of the sun (i.e., direction of sunrise, altitude of sun, etc.) on a shadow plot would be advantageous in terms of connecting teachers' reasoning to their diagrams and explanations.

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