

The Sky as a Topic in Science Education

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ABSTRACT: The concepts of sky and visibility distance, as perceived by different learners, are investigated for the first time as a subject of a science education research. Mental models of students with regard to the subject were elicited. They were interpreted in terms of two-level hierarchy: schemes and facets-of-knowledge (defined in the paper). Our results suggest that many students do not consider sky to be a scientific (physical) concept. The majority perceives the sky as having an oblate profile. Among the parameters that determine this profile were mentioned daytime, atmosphere, geometry of the situation, and weather conditions. The students hold two major explanatory views (schemes) with regard to the sky: “the sky is the atmosphere” and “the sky is the appearance of space.” With regard to the visibility distance, the two following schemes prevail: “vision weakens with the distance” and “natural obstacles determine vision distance.” No significant correlation was found between the views regarding the sky appearance and the vision distance. Students do not relate Moon illusion to the profile of sky or visibility distance. The notions of sky and visibility distance are argued for inclusion into science curriculum, and implications of the findings to a constructivist instruction of the considered concepts and phenomena are discussed. © 2004 Wiley Periodicals, Inc. *Sci Ed* **88**:574–593, 2004

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INTRODUCTION

If we wonder about the shape of the sky, is it a spherical dome, or some other shape? Does this shape change? What can influence this shape? Is our perception based on scientific evidence, or is our concept a cultural or perception-inspired conjecture?

An extensive review of textbooks in science, general physics, optics, and astronomy testifies to the fact that “sky,” as a scientific notion, does not appear in the curriculum of such courses.¹ This, despite the obvious fact that few concepts regarding natural environment can compete with sky in relevancy and familiarity to students; it is literally a subject of everyday (and night) observations. Like air, water, and earth, the sky belongs to the most basic environmental concepts that constitute our representation of physical ecology. Hence, once noticed by an individual, the deficiency in scientific coverage of this concept will remain pronounced in his/her personal knowledge.²

It was the sensitivity to students’ curiosity about the world around that caused particular efforts to improve the scientific contents of science courses, as for example, within the STS approach to teaching (DeBoer, 1991; Fensham, Gunstone, & White, 1994). Constructivist theory (Driver & Bell, 1986; Duit, 1995; Duit & Treagust, 1995, 1998; Glasersfeld, 1989, 1992; Tobin, 1993; Tobin, Tippins, & Gallard, 1994) goes further and suggests fortifying the teacher with the knowledge of the ideas and beliefs students possess regarding the scientific concepts that they learn in order to induce the required conceptual change of the pertinent intuitive knowledge. The knowledge of the ways to encourage this process belongs to the realm of pedagogical content knowledge (Shulman, 1986)—an extremely important constituent of teacher competency.

In this paper we took the first step in investigation of people’s ideas and views concerning the notion of sky, including the perception of its shape and the parameters that might determine it (Cohen & Galili, 2001). We also checked students’ ideas with regard to the visibility distance and the phenomenon of “moon illusion” hitherto not investigated. Although each of these by itself presents an interesting and important topic, we considered these issues in the same study, because they are integrated within the scientific coverage of the topic (Cohen & Galili, 2001), and it is important to map the pertinent knowledge of the learners in one integrated picture.

ORGANIZATION OF THE LEARNERS’ KNOWLEDGE

The importance of students’ ideas and views is a commonplace in science education discourse. Intuitive interpretations of natural phenomena often contradict the scientific explanations, establishing so-called alternative conceptions,³ usually tenacious and resistive to the following change (e.g., Galili & Bar, 1992). Special conditions (Posner et al., 1982;

¹ We restricted ourselves to the last decade and the books published in English (United States). We examined five types of textbooks, which could present the concept of sky as relevant to their scope: (1) Textbooks in Physical Science for nonscience majors in colleges and universities. Five such books were checked (e.g., Hazen & Trefil, 1996); (2) Physics textbooks for advanced placement high school courses and colleges. Twelve such books were checked (e.g., Hewitt, 1992; Serway & Faughn, 1995); (3) Physics textbooks for scientists and engineers, and science majors in universities. Fourteen such books were checked (e.g., Tipler, 1999); (4) Astronomy textbooks for colleges and universities. Ten such books were checked (e.g., Chaisson & McMillan, 1997); and (5) Optics textbooks for university course. Four such books were checked (e.g., Hecht, 1998).

² Physics courses often include an account of why the sky is blue but not more than that regarding the sky.

³ An extremely vast bibliography including about 6000 references to the studies on alternative conceptions of students learning sciences can be found in Duit (2003).

Strike & Posner, 1992) and instruction strategy (e.g., Galili, 1996) are required to promote a conceptual change in the course of the learning with regard to a particular subject.

It is less agreed what structure is to be ascribed to novice knowledge, if at all. In general terms, one can address its constructs in terms of “naïve” or “intuitive” mental models (Genter & Stevens, 1983). The latter notion might be however refined. Here we briefly mention some approaches to this subject in order to introduce the one we chose to represent mental models of the students in our study.

Following Piaget (1966) it was realized that people spontaneously develop explanatory knowledge regarding their natural environment, leaving no vacuum of views or ideas with regard to the subject of relevance. Even in the absence of formal instruction, people inevitably develop, based on personal experience, their intuitive concepts of energy (e.g., Trumper, 1993), force (e.g., Watts, 1983), light-ray (e.g., Galili, Goldberg, & Bendall, 1993), mirror image (e.g., Bendall, Goldberg, & Galili, 1993), sky, etc. Furthermore, explanatory cognitive patterns are constructed to account for the phenomena and artifacts of natural environment. The simplest and often vague conceptual association of this kind, individually created, is Piaget’s *schema* (e.g., weight of an object is perceived by a child through a schema relating the object to the muscular effort required to hold or move it).

To describe students’ account for physical situations Minstrell (1992) introduced the notion of facets-of-knowledge. These are explanatory patterns of knowledge, by which students make sense of particular experiences (e.g., “heavy objects fall faster,” “lens inverts the image,” “mirror creates and contains the image”). Facets-of-knowledge represent what is called “common sense” considerations, reflecting straightforward interpretation of a situation, unrestricted by scientific constraints and thus often incoherent with scientific knowledge. Normally, facets-of-knowledge are strongly context-dependent and could be inconsistent between themselves. Salient features of the situation often play a central role. For instance, the obvious fact of the greater damage of a small car in a collision with a truck shapes the view of “a greater force exerted by the bigger mass in a collision”—a common facet-of-knowledge conflicting the tenet of action–reaction symmetry of force interaction in physics. Facets-of-knowledge may also include strategies, rules, types of drawings, and other patterns of behavior that students use while entangling with a problem, situation, etc.

Later on, facing an extreme multiplicity of the documented facets-of-knowledge (reflecting a great veracity of the situations being explained), a hierarchy of the known facets was introduced (e.g., Galili & Hazan, 2000a, 2000b; Galili & Lavrik, 1998). A two-level hierarchy was suggested to distinguish between the facets of a rather global, less context-dependent meaning (scheme-of-knowledge) and a more concrete facets-of-knowledge, presenting implication for a particular situation of a certain explanatory idea, stated by a scheme-of-knowledge. Thus, each scheme appears as producing a cluster of affiliated facets with regard to different contexts. For example, the scheme of a holistic image (a wrong conception) may manifest itself in numerous facets (each a misconception) with regard to mirrors (“one needs a vertical mirror of the height of the object to see its full reflection”), lens (“half lens produces half image”), prisms (“the triangular prism splits the image into two ones, each observed”), etc. (Galili & Hazan, 2000; Galili & Lavrik, 1998). Unlike p-prims (DiSessa, 1993; Smith & DiSessa, 1993; Hammer, 1996, 2000) and “intuitive rules” (Stavy & Tirosh, 1996; Tirosh, Stavy, & Cohen, 1998), spontaneously developed by children, schemes may be induced by a particular instruction in a science class (e.g., Galili, Goldberg, & Bendall, 1993; Galili & Kaplan, 1996).

The facets-scheme representation of knowledge structure may not only illuminate the cognitive rationale of the learner [thus it is reasonable to believe that the schemes-of-knowledge possessed by an individual guide him/her in the process of learning, serving as an advanced organizer of his/her accretion of knowledge (Ausubel, 1968; Tamir, 1993)], but also facilitate

teaching strategies addressing the core problems in the ocean of their various reflections. Schemes may guide the assessment of knowledge following up its evolution in the learners. Thus, schemes might represent, as some studies state, hybrid (Galili, Goldberg, & Bendall, 1993) or synthetic (Vosniadou, 1994) mental models, mixing in them scientific and naïve elements of knowledge. Some hybrid schemes will be replaced in the course of further learning, but others may remain in the knowledge of individuals. Finally, in the perspective of curricular designers, the knowledge of schemes may guide the development of materials effective in remedy of students' alternative conceptions. Such materials put the naïve models (schemes) in the focus of conceptual critique (Galili & Hazan, in press; Goldberg, 1997).

SUBJECT MATTER BACKGROUND

The subject matter background of this study includes three aspects. Firstly, hitherto in science education research, the concept of sky was not in the list of research subjects. Nussbaum (1981), Baxter (1989), Galili and Lavrik (1998), and others explored novice knowledge with regard to astronomical concepts: earth gravity, the shape of the earth, day and night, phases and eclipses of the moon, and seasons. The present study added *sky* and *visibility* to this list, drawing on the importance of these concepts and their being familiar to the wide public.

Secondly, the history demonstrates people's cultural interest in the sky concept, elaborated in several descriptive models.⁴ Gradually, in the course of history, the naïve concept of sky (as a spherical firmament literally arching the earth as a sort of a dome) gave the way to the formal concept of *celestial sphere* (a pure abstract concept), sufficient to represent the contents of the astronomy course. The concept of sky in its old meaning of a dome remained in the artistic and humanitarian realm, usually lacking any scientific meaning. The intuition with regard to this concept became irrelevant for scientific literacy.

Thirdly, in science, the concept of sky was revived in the domain of atmospheric science, where it was related to the process of light scattering in the atmosphere. It appeared that the manner in which the light of the sun scatters in the atmosphere determines the perception of the sky shape, as a vault of a spherically oblate dome, much closer to the observer in the vertical direction than in the direction to the horizon (Cohen & Galili, 2001).⁵ It was also understood that the perception of a sky dome exactly corresponds to the dependence of the visibility distance on the direction of observer's sight in the presence of atmosphere⁶ (Cohen & Galili, 2001). This understanding made available physical explanation of such phenomenon as moon illusion. Until recently, the latter, as well as

⁴ It is not a place to review the ideas regarding the sky notion. We mention only few examples: sky as a body of a goddess Nut (old Egyptian culture), flatten in the center (Leeming, 1976; Tauber, 1979), sky as a body of a snake (old Hindu conception, Leeming, 1976; Tauber, 1979), sky as a shell, a segment of a sphere (Chaldean conception of the Firmament adopted in Thales' universe, Leeming, 1976; Tauber, 1979), sky as a half sphere, somewhat flatten (Leeming, 1976; Tauber, 1979), sky as a system of crystal spheres (Eudoxus' concept). The Greek conception of a spherical sky was transformed into the notion of celestial sphere considered in astronomy (e.g., North, 1997, p. 1).

⁵ The central role of the sunlight scattering immediately implies the difference between the sky perception during the daytime and that at night. During the night, the dome of the sky indeed appears a semispherical, like in the planetarium.

⁶ People perceive a sky firmament as an oblate spheroid, flattened above their heads because of the fact that the visibility limit is closer when looking in the vertical direction than when looking more horizontally. This is the result of the rapid decrease in the number density of air molecules, dust, and other particles suspended in the atmosphere, as the elevation from the ground increases. The lifelong individual experience of observation of clouds, birds, airplanes, etc. determines the sky profile in the human perception.

the sky perception, was treated mainly in psychology (Hershenson, 1989).^{7,8} Another important and quite surprising fact, usually not mentioned in introductory courses, is that visibility distance of the objects,⁹ which are seen only because of the scattered light, is determined by the contrast of the observed object with its immediate environment (Hershenson, 1989).

In light of all stated, and being motivated by the accepted value of scientific literacy in modern society (Fensham, 1986), we argue to consider whether sky concept and visibility distance should enter the science curriculum. It is upon science education research, however, to prepare the necessary information about students' ideas of the subject. This activity will match the constructivist understanding of the conditions necessary for the effective instruction.

METHOD

Sample

Our sample was comprised of six groups of subjects at four age levels: Group P—pupils of two high school classes,¹⁰ an 11th-grade homeroom class (P_1 , $N_1 = 24$), and a 10th-grade physics class (P_2 , $N_2 = 28$)¹¹; Group S—university freshmen in earth science (S_1 , $N_3 = 24$), and social science (S_2 , $N_4 = 50$); Group T—graduate students at the science-teaching department ($N_5 = 16$), who are active high and junior-high science and mathematics teachers; Group C—elementary school pupils, aged 8–11, randomly sampled from three classes ($N_6 = 60$).

Procedure

The study was planned as a diagnostic one for the novelty of its topic. The pertinent knowledge on the subjects was probed in a written test. Permission was obtained to reach each group at the time of a regular class instruction thus removing the necessity to ask for participation. A specially developed questionnaire (see appendix) was constructed of qualitative questions. The content validity of the questionnaire was provided by the fact that the research team represented three disciplinary domains: educational research, atmospheric science, and physics.

Young subjects were also asked to use drawings in responding to a particular question (see below). This was done in order to help children more effectively express their views or beliefs. Drawing presents a more intuitive mode of expression, permitting young subjects

⁷ Thus, as a rule, moon illusion (the apparent increase of moon or sun disc when they are observed next to the horizon) is not even mentioned in science courses and their textbooks. Only the texts that consider psychological effects of vision may address this phenomenon (e.g., Gregory, 1997).

⁸ For example, in Minnaert (1940) we read:

When we survey the sky from the open fields, the space above us does not generally give us the impression of being infinite, nor being a hollow hemisphere spanning the earth. It resembles rather, a vault whose altitude above our heads is less than the distance from ourselves to the horizon. It is an impression and not more than that, but for most of us a very convincing one, so that its explanation must be *psychological* and not *physical*. (our emphasis)

⁹ The scientific meaning of *visibility distance*, essential for explanation of sky perception, is usually included only in university level Atmospheric Science curriculum.

¹⁰ We chose to distinguish between elementary and high school students, on the one hand, and university students, on the other, by referring to the former as "pupils."

¹¹ Physics is an elective discipline in Israeli high school.

TABLE 1
Students' Perception of the "Sky" Term (Percentage)

Identification of Sky	P ₁	P ₂	S ₁	S ₂	T
Scientific	58	43	67	38	31
Nonscientific	25	50	33	44	25
Both (context-dependent)	17	7	–	18	44

P, S, T—group labels of the subjects, as defined in Sample section. Group C was not asked this question. The numbers in bold signify the preferable category within the group (students, teachers, pupils).

to avoid difficulties of using textual descriptions, explicit articulation, and notions unknown to the child.¹²

The subjects were instructed regarding the informal character of the test (anonymous and nongraded). They were encouraged to explain their answers. One class period (45–50 min) was given to fill the questionnaire form; students normally sufficed with about 30 min. All of the students replied, although not all the questions were informatively answered (the "I do not know" answers were taken into statistical account).

To process the accumulated responses, two of the authors independently read the answers and introduced their initial categorizations. The results then were matched and discussed by all three investigators, resulting in final categorization and interpretation. Much attention to the categorization reflected the novelty of the research topic. There was, however, a great extent of agreement in the interpretation of the collected responses.

RESULTS AND THEIR INITIAL INTERPRETATION

The test questions can be divided into three groups: Q-1 to Q-4, which concern the nature and shape of the sky, Q-5 that concerns the visibility distance, and Q-6, addressing the "moon illusion." We will address the results corresponding to these groups.

The Sky

The Sky as a Scientific Concept, Q1. The concept of sky is similar to other general concepts in science such as energy, force, potential in the sense that it belongs to the everyday vocabulary and, at the same time, presents nontrivial scientific meaning, incompatible with the former use. Such situations originate frequent debates on how to reconcile both senses in educational practice. The term sky apparently causes even greater confusion. In response to our question to identify sky as a scientific or nonscientific term, the answers split regardless of educational background or age of the subjects (Table 1). Even among students studying earth sciences (Group S₁), who took astronomy and atmospheric science courses, not more than 67% included sky in the list of scientific terms. The second was Group P₁ (58%). Social science students (Group S₂) and 10th-grade pupils (Group P₂) majored in physics, though never encountered with "sky" in formal studies, showed only a

¹² It is common in psychological tests to use the form of drawing to free the subjects from the explicit articulation of their views regarding the topic that might be novel to them conceptually (e.g. Piaget, 1966).

TABLE 2
Students' Views Regarding the Shape of the sky (Percentage)

Shape of the Sky Vault	C	P ₁	P ₂	S ₁	S ₂	T
1. Spherical	2	26	14	30	8	–
2. Oblate (and flat)	23 (75)	44 (22)	61 (11)	57 (4)	62 (18)	63 (31)
3. Prolate	–	4	4	9	–	–
4. Infinite (and undefined)	–	4	10	–	5 (7)	0 (6)

C, P, S, T—group labels of the subjects, as defined in Sample section. The numbers in bold signify the preferable category within the group.

slight preference for the nonscientific sense of the term. Only a few in Groups P₁, P₂, S₂, and none from S₁, considered “sky” as belonging to both lists. This reasonable response (not suggested explicitly) appeared mainly in Group T (science teachers). Such were the answers¹³:

Sky is a material concept, as well as a spiritual one. It depends on the context in which we use it. (Group S₂)

A student who attributed sky to the nonscientific list wrote:

Sky acts on our feelings and mood. (Group P)

One who chose the scientific list wrote:

Sky is a scientific term for it is related to other scientific concepts. (Group P)

Our data reflect certain uncertainty of the subjects in their addressing the notion of sky and no particular physical features of sky were mentioned, even when the taken choice was explained.

The Shape of the Sky, Q2. The question probed the perception of the shape of the sky asking to choose one out of the four profiles presented. An opportunity to respond by another shape was also given. The most common choice of the children in Group C was the drawings depicting sky in a flatten profile. Few children drew the profile different from those depicted in Figure A1 (Appendix). We then scored the personal drawing as better representing the individual perception (see footnote 15). The preference for the flatten profile remained in other groups (Table 2).¹⁴ In Group T about 30% chose the “flat sky”; only few selected the “high-dome” or “another-shape” options. Some of the latter responded with “undefined” or “infinite” for the sky profile. Our high school students (especially Group P₁) were often unsure and mentioned that the question puzzled them: they never thought of the sky as possessing a shape.

¹³ From here on we exemplify the responses of our subjects by a typical response, and mention the sample group from which the quote was taken.

¹⁴ We combined “flat” and “oblate” responses into one category since these two are rather close—especially in individual drawings—reflecting similar perception of “flattering” of the sky dome. This is in contrast to other perceptions.

Parameters Influencing the Shape of the Sky, Q3 and Q4

Day and night. Regarding the night sky, about 75% of Group T, 65% of Group P, and 50% of Group S answered that the sky remains in the same shape regardless of the day or nighttime. (In this section we merge the data of the subgroups P₁ and P₂ (Group P), as well as subgroups S₁ and S₂ (Group S) because of the few responses to the question).

Absence of atmosphere and the moon's sky. In response to Q4, about 60% of the pupils and students, and 25% of the teachers displayed the belief that the shape of the sky on the moon is different from the night sky on the earth. Most explained it by the atmosphere. The answer “the moon has no sky” seemingly represents this view, identifying sky with atmosphere and implying “no atmosphere–no sky” relationship:

Since the moon has no atmosphere, the sun rays are not refracted, and the moon's sky has no color or shape. (Group P)

Science teachers expressed another view; 75% of Group T wrote that the shape of the moon's sky should be similar to that of the earth at night regardless of the atmosphere. In agreement, most stated that the shape of the earth's sky would remain the same without the atmosphere, explaining:

The moon's sky is not different from the earth's night sky because [in both] the person is observing the space above a sphere. (Group T)

The shape of the earth. Many subjects mentioned horizon and the earth's roundness as the factors influencing the shape of the sky on the earth (or another planet), regardless of the atmosphere:

The shape of the sky is determined by the shape of the earth. (Group T)

The sky surrounds the earth, therefore it [the sky] is spherical. (Group S)

The moon's sky may look more spherical because the moon is a smaller sphere. (Group T)

If the earth were much bigger I may not be able to see the roundness [of the sky]. (Group T)

The sky is like the earth—If the earth is flat so is the sky. (Group T)

In a country up North, the shape of the sky is more curved. (Group T)

Two students of Group S mentioned the oblateness of the earth globe as determining the sky shape.

Other parameters. Around 50% of the students (Group S) and 20% of others suggested weather conditions to be a parameter of possible influence on the shape of the sky:

During stormy weather [cloudy sky] the feeling is that the sky is flatter and lower. (Group S)

Among the other parameters mentioned to a lesser degree were the color of the sky (at different hours of the day), air density, dust particles, pollution, and geographic location.

On the basis of the responses to the first four questions we can elicit two major mental models (schemes-of-knowledge¹⁵), which, we believe, represent the main ideas with regard to students' conceptions of the sky and its shape.

¹⁵ As was defined above, “scheme-of-knowledge” is an explanatory pattern of general form. “Facet-of-knowledge” presents a realization of a certain scheme as triggered by a particular setting.

The first scheme, SS-I, is “The sky is the atmosphere surrounding the earth.” This scheme reflects the idea that what we see above us in the open-air environment is the atmosphere. Accordingly, the moon has no sky, since it has no atmosphere. One can recognize this conception in such quotes as:

The sky is the firmament—you may say it is the atmosphere layer around earth. (Group T)

Had the earth no atmosphere, there would be no sky. (Group T)

The second model (scheme), SS-II, is “The sky is the appearance of the space to the observer standing on the ground.” Students wrote:

... There is no connection to the atmosphere. The sky is the space I see above the ground. (Group P)

The shape of the sky will not change if the earth had no atmosphere. (Group P)

In contrast to the first scheme, this conception implies that the moon’s sky is similar to that of the earth, since in both cases the observer is standing on a spherical surface. The distribution of these two schemes among the groups of our sample is presented in Table 3. Since these results are based on the answers to the questions (Q-2-1, -2, -3, -4) Group C was not asked. We refrained from inferring an abundance of these schemes among the children.

Visibility Distance (Vision Depth)

The amount of data explaining disappearance of objects moving away from the observer (Q-5) appeared sufficient to infer not only the models (schemes) of the corresponded knowledge, but also to identify its secondary, with respect to generality, constructs—facets-of-knowledge—and evaluate their frequencies. As introduced above, the facets-of-knowledge can be interpreted as refinements of the idea expressed in the correspondent scheme. Facets are often articulated by wordings utilized by the students themselves. For brevity and convenience of the presentation we display the results already after such a hierarchical categorization. Practically, in the course of the analysis, the facets of knowledge were identified first, and only further exploration of their meaning, the discussions between the investigators, yielded the establishment of the schemes. Table 4 reproduces the three schemes and their affiliated facets, as elicited regarding the visibility distance of the observer on the ground. Since the data in subgroups P₁ and P₂ were close, we present them here by their average. A similar approach was used with regard to the subgroups S₁ and S₂.

TABLE 3
Schemes-of-Knowledge Regarding the Nature and the Shape of the Sky (Percentage)

Scheme	P	S	T
SS-I: The sky is the atmosphere	63	57	25
SS-II: The sky is the appearance of space to the observer on the ground	37	43	75

P, S, T—group labels of the subjects, as defined in Sample section. The numbers in bold signify the preferable category within the group.

TABLE 4
Schemes and Facets-of-Knowledge Regarding the Visibility of Receding Objects (Percentage)

Schemes	Facets	C	P	S	T
VS-I: Vision weakens with the distance (between us and the object(s) we are viewing)	1. Our eyes are limited in the distance they can see	12	20	17	7
	2. Vision works within an area (field of vision) limited in all directions	41	18	8	7
	3. We stop seeing things since they look smaller and smaller as the distance increases between them and us	21	24	6	–
	4. One stops to see the object because the angle subtended by it (angle of vision) diminishes with the increase of distance	–	2	10	7
	5. We cease to see the objects because the light they reflect (radiate) weakens (decreases) with the distance	–	–	17	7
VS-II: Natural obstacles of the environment determine [the depth of] vision	1. Since we look at straight lines but the earth is round, we stop seeing things when they disappear behind the horizon	8	18	25	15
	2. Natural obstacles (clouds, air masses, and mountains) limit our vision	15	6	5	7
VS-III: Hybrid schemes	Combinations of facets of both schemes				
	1. I-1+II-1	1.5	–	5	22
	2. I-1+II-2	1.5	4	–	–
	3. I-2+II-1	–	–	3	14
	4. I-2+II-2	–	4	2	7
	5. I-3+II-1	–	2	–	7
	6. I-4+II-2	–	2	2	–

C, P, S, T—group labels of the subjects, as defined in Sample section. The numbers in bold signify the preferable category within the group.

Scheme VS-I. “Vision weakens with the distance.” This scheme stipulates the visibility, that is, the ability of the observer to perceive an object, by its distance to the observer. The scheme implies that starting at some distance, vision is ineffective, and the observer can no longer detect the object. This scheme was recognized as having five facets.

The holder of the first facet regards the eye as a naturally limited instrument, restricted in its function. The second facet claims the limit of the vision range stating that if the object is “out of the field” one cannot see it. Both these facets limit vision ad hoc:

Our eyes are not sensitive enough and [when they cannot see] our brain can't process the data. (Group S)

The difference between the facets is in the emphasis they make: the first emphasizes the limitedness of the eye ability (with a better instrument one could see farther), whereas the second facet emphasizes the area, the field of vision. Many students who solely stated the limited area (“distance,” “range”) of vision resembled by their answer the frequent manner of naive response, in which the student inverts the question statement, ignoring any mechanism involved:

Q: Why do we cease to see a receding object [an object at a long distance]?

A: It is because the objects are too far we cannot see them. (Group C)

We should mention, however, that an explanatory mechanism, as often utilized in science, is rarely addressed in everyday experience. The responses represented by the first two facets of VS-I are typical for younger learners (Piaget, 1969). They appeared in more than 50% of Group C, and almost 40% of Group P.

The third facet of VS-I presents another significant pattern of explanation, used by the younger subjects. It states the limited visibility distance due to the fact that objects “become smaller,” eventually collapsing to a point for the observer:

The object becomes so small that we can't see it. (Group C)

The same metaphoric presentation but more elaborated was in

The object becomes so small that the light rays reflected from it to our eyes can't create its picture in our mind. (Group S)

The fourth facet of VS-I seems to be an expansion of the third. Expressed by adults, mainly student-teachers, this idea attains a scientific form, addressing the visual angle subtended by the object. When decreased this angle surpasses the threshold of sensitivity, the vision resolution:

As an object recedes, the visual angle decreases, until our eyes cannot distinguish the object which looks like a point. (Group T)

The last facet of VS-I is also clearly scientific in form. This facet claims that the eyes cease to see the objects because of the reduction of light intensity as the distance from the object increases. The mentioned decrease indeed takes place. Only earth science students and student-teachers expressed this view:

The light reflected from the object is diminishing. (Group T)

The light rays disperse and do not reach our eyes. (Group S)

Our eyes are not sensitive enough [to this weak light]. (Group S)

Unlike the first two facets of this scheme, the emphasis put here is transferred on the light intensity, from the eye's ability (“weakening of vision,” “vision limitation”). In their answers, the students did not manipulate with the concepts of “light flux” or “light rays.” Only one student mentioned the background illumination or ambient light, which might influence visibility distance.

Scheme VS-II. “Natural obstacles of the environment determine [the depth of] vision.” This scheme stipulates visibility distance by the natural obstacles to vision. The scheme was recognized in two facets. The first one explains the limit of visibility distance by the horizon, or by the curvature of earth, which hides the objects when they move “behind it” (Figure 1). There, they cannot be any longer reached by the straight-line vision, because of the curvature of the earth:

The airplane is flying over the sphere, therefore we can't see it on a straight line. (Group P)

The direct implication of this understanding [this facet-of-knowledge] is important: given no horizon (i.e., flat earth), the visibility is not limited. Here the maximum contrast with the scientific conception of vision depth is reached.

The understanding within this facet revives the Aristotle's argument for earth sphericity (mentioned by one student) that described gradual appearance (or disappearance) of a ship to the observer on the shore: from the pole of the mast of the ship to its deck. Regarding such “disappearing” objects, children said:

They go away beyond the horizon, to another place. (Group C)

Another view, the second facet of VS-II, observed rather equally in all groups, ascribed the limit of visibility to other obstacles to vision—clouds, mountains, and masses of air. The students mentioned weather conditions, clouds, and dust particles, or sunlight itself, obstruct vision and prevent objects from being seen. One child wrote:

The sky is composed of several layers, and the object enters one of them [and disappears].
(Group C)

Certain responses represented a composite (“hybrid”) type of reasoning. This explanatory pattern includes elements of both schemes (VS-I, VS-II) in a variety of facet combinations. Such response, which incorporated more than one reason to explain, appeared mostly in Group T (Table 4).

Finally, Table 5 presents the overall distribution of schemes with regard to the visibility distance. The decrease of scheme VS-I with age (or educational level) is pronounced, whereas the frequency of Scheme VS-II remains steady, around 20%. Scheme VS-III becomes more popular as the age of the subjects grows.

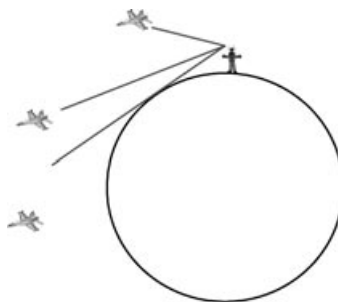


Figure 1. A reproduction of the drawing provided by several subjects to explain that the visibility of the on-ground observer is limited by the horizon [due to the sphericity of the globe].

TABLE 5
Schemes-of-Knowledge Regarding Visibility of the Objects Receding from the Observer (Percentage)

Schemes	C	P	S	T
VS-I: Vision weakens with the distance	74	64	58	28
VS-II: Natural obstacles of the environment determine [the depth of] vision	23	24	30	22
VS-III: Hybrid schemes	3	12	12	50

C, P, S, T—group labels of the subjects, as defined in Sample section. The numbers in bold signify the preferable category within the group.

The Apparent Increase of Moon (Sun) Size Near the Horizon

Most subjects of our investigation showed familiarity with the phenomenon of the “moon illusion.” They chose the enlarged moon appearance when observed near the horizon (Table 6). The physics class (Group P₂) was, however, an exception where many refrained from answering this question. Few subjects explained the enlarged disc as a real effect, caused by the moon’s approach to the earth. Among other responses were explanations involving atmospheric refraction of light and statements (though unexplained) regarding the enlargement as illusion. Students’ suggestions for experiments to test their assertions included using photography, pinhole camera, and examination of appearance of a ball placed at different distances (as illustration of the enlargement as a real effect).

DISCUSSION

This study used the previously developed interpretation of knowledge organization to explore the understanding of several topics of subject matter all related to the concept of sky. The elicited mental models (schemes-of-knowledge) of sky and visibility present the major findings. It is informative to juxtapose them (Table 7).

Each of the schemes represents a reasonable idea with regard to the subject and not a simple misconception. Schemes SS-I [sky is the atmosphere] and VS-II [obstacles determine vision distance] are somewhat more concrete, showing relationship between the subject to explain (sky, visibility) and certain physical objects (atmosphere, obstacles). At the same time, schemes SS-II [sky is an appearance of space] and VS-I [vision weakens with the distance] are less concrete, more abstract, and declarative. We did not find any significant correlation between holding a particular model with regard to the sky and the same person’s mental model regarding visibility distance. This fact indicates that the scientific account,

TABLE 6
Students’ Views Regarding the Apparent Size of the Moon (Percentage)

Moon’s Perceived Size	P ₁	P ₂	S ₁	S ₂	T
1. Enlarged near the horizon	63	41	88	82	69
2. Same size as near zenith	12	52	8	8	25
3. Enlarged near zenith	25	7	4	10	6

P, S, T—group labels of the subjects, as defined in the Sample section. The numbers in bold signify the preferable category within the group (students, teachers, pupils).

TABLE 7
Schemes-of-Knowledge, as Recognized in Students' Responses with
Regard to the Nature of Sky and Visibility Distance

Sky Schemes (SS)	Visibility-Distance Schemes (VS)
SS-I: "The sky is the atmosphere surrounding the earth"	VS-I: "Vision weakens with the distance [between us and the objects we are viewing]"
SS-II: "The sky is the appearance of the space above to the observer on the ground"	VS-II: "Natural obstacles of the environment determine [the depth of] vision"

which relates the sky perception with the visibility distance, is nonintuitive and cannot be spontaneously discovered by the student. The requirements of a special instruction further increase, since all the intuitive knowledge (the schemes) mentioned above present apparently reasonable ideas. These ideas match the common sense and thus challenge the scientific account of the subject. The situation with regard to both concepts (sky and visibility distance) is however not the same.

In one scheme, the sky is considered to be the atmosphere itself (SS-I). The sky, then, serves only as a name for the "object" directly observed. This belief could guide those who stated the same sky shape during day and night. Indeed, how can the shape of the same *object* change, or depend on the observer and his vision? For this very reason, since Aristotle the "flattened sky" was stated to be a mere illusion. The claim of the sky not changing from day to night contradicts, however, to the evidence of senses (Hershenson, 1989; Minnaert, 1940) and the scientific account, as well.

The other scheme identifies the sky with the appearance of the space to the on-ground observer (SS-II). This idea is more abstract and ontologically different. In this form, sky may resemble the concepts representing a state observed, such as movement or brightness. Furthermore, identified with geometrical space, sky coincides with the concept of "celestial sphere" utilized in astronomy. Traditionally, astronomy courses (and so the textbooks) present the stars placed "at the same distance" on a spherical dome subtending the line of horizon (the shape of a planetarium). In our sample of students, this perception was shown by about 30% of Group S.

Both schemes of the *sky* conception are intuitive and do not address any mechanism. Therefore, although different from the scientific explanation, they cannot really compete with it when an explanation of the view is required. Thus, one can construct an instruction based on a refinement, instead of rejection of the already existing ideas (Grayson, 1996). The situation with the sky concept is thus better than with regard to the learning of Newtonian paradigm where the scheme "motion implies force" (e.g., DiSessa, 1983; McCloskey, 1983; Galili & Bar, 1992) presents a strong ontological rivalry of the Aristotelian (and later, medieval) physics with the Newtonian one (e.g., Dijksterius, 1986).

The situation is different with regard to the *visibility distance*. Visibility concept, although basing straight on the sense experience, is addressed only in specific university courses. Worthy of notice, the schemes of visibility, VS-I and VS-II, reflect plausible reasoning. Both, however, conflict with the scientific account for the depth of vision of objects in the atmosphere. Thus, for example, the idea that the limit for visibility is caused by attenuation of the light signal from the object (the last facet of the scheme "vision weakens with the distance"; Table 4) seems quite persuasive. In fact, it is indeed the case, but in the absence of atmosphere. In the presence of atmosphere, however, another physical parameter determines

the visibility of the objects that are seen due to the reflection of light, their contrast with the background (Cohen, 1975). Likewise, within the second scheme (VS-II), horizon or other obstacles would indeed limit the visibility distance in the absence of atmosphere.

Students' ideas with regard to visibility distance can be directly related to their views regarding vision in general (Galili & Hazan, 2000a). Thus, the scheme, which includes claims of "vision is weakening," as a natural fact (VS-I), is compatible with the Spontaneous Vision Scheme that implies vision performed "naturally," by a simple act of looking (a mere presence of the eye).¹⁶

The issue of *optical illusion* in a regular instruction deserves a special concern. It is seemingly common that formal instruction does not address illusions, as if ascribing them to the realm of psychology.¹⁷ Thus, as mentioned above, "moon illusion"—the apparent increase of the moon when observed near the horizon, is not addressed in a regular physics instruction. Our data shows that students are commonly aware of this phenomenon and some even consider it as a real physical effect, caused by the approaching moon. This fact raises the question of whether ignoring illusions, especially the frequently observed ones, presents an adequate educational policy.

One may identify three educational conceptions regarding the phenomena coverage by a physics course. Within the *first*, the instruction excludes all those phenomena that are dependent on the observer (such are illusions). In addition, seeking simplicity, the instruction often avoids addressing the phenomena, which essentially involve real conditions (such as atmosphere in optics, friction in mechanics, etc.). The focus is solely on the ideal cases, exemplars representing physics laws, "undisturbed" by the reality. This approach is often used in the introductory courses for nonscience majors, although the benefits of such for the learners are questionable since the reality often emerges as contradicting with the physics of the instruction (friction and heat dissipation are ubiquitous, there is no observation without atmosphere and so on).

The *second* approach is broader. This type of instruction does include the phenomena that are modified with the real conditions (friction, heat dissipation, atmosphere refraction are included). Such are usually the physics courses for a more advanced level. For example, such a course would address the oblateness of the sun disc and its being unusually red at sunset or sunrise. However, all the phenomena included in such an instruction are observer-independent, that is, can be registered by physical apparatus (e.g., a camera recording the "distortion" of the sun disc).¹⁸

The *third* approach to physics instruction encompasses also the phenomena that are *observer-dependent*, that is, include *subjective* elements. For instance, in relation to this study, we can mention such phenomena as the halos observed around light sources and color perception. "Moon illusion" also belongs to this type. Although those phenomena cannot be registered directly by instruments, their common feature is that despite the elements of psychological nature, their account essentially requires disciplinary knowledge (such as scattering of light, light dispersion and composition, the knowledge of perspective and optical imagery).

¹⁶ One can match even the facets of knowledge within these two schemes. For instance, the first two facets of VS-I in this paper are similar to the first two facets of the Spontaneous Vision Scheme in the cited paper.

¹⁷ One can get this impression by browsing science textbooks, commonly used in science courses in schools and colleges.

¹⁸ The issue of observer dependence is complex. While illusions present a subject of psychology, science educator never forgets that the account of relativistic and quantum phenomena essentially includes observer. For example, Lorentz force for the magnetic interaction is observer-dependent. We do not touch on this issue here.

Adoption of any approach, from the three mentioned, depends upon the adopted educational philosophy and policy—a variety of considerations and values. The first two approaches are common, while the third presents a subject of a special debate: why should physics curriculum incorporate interdisciplinary phenomena? The reservations against such curricular change are known: the amount of a “regular” material is already too big, the disciplinary knowledge might be diluted, textbooks do not provide necessary support for the learner, teachers might be less competent in the interdisciplinary matters, and so on. Each of these reservations deserves a special consideration that we cannot afford here. These all should be weighed against the points of possible benefit that can motivate and encourage science educators to consider the observer-dependent phenomena nevertheless.

Ausubel (1968) claimed meaningful learning to be the goal of learning process. Meaning is determined by the multiplicity of conceptual connections, in other words, multitude and veracity of contexts related to the subject of learning. Interdisciplinary topics provide such multiconnectedness thus enriching students’ knowledge. For instance, to understand the profile of the sky one needs to grasp the idea of light scattering in the atmosphere and to learn about visibility criteria and the way humans evaluate the distance to the observed objects.

More recently, Fensham (1986) advocated the change of curriculum in favor of the topics *relevant* to the learner. He claimed *science literacy* to be among major goals of science education for the wide population of students. This approach consolidated under the title Science–Technology–Society (DeBoer, 1991). Interdisciplinary topics, such as the shape of the sky, visibility distance, and “moon illusion,” apt to this approach by matching general curiosity and are thus relevant to the students.

IMPLICATIONS FOR INSTRUCTION

The findings of this study can fortify the inclusion of sky and visibility distance into the physics curriculum. To reach a meaningful conclusion, one may say that the constructivist type of instruction addresses pertinent constructs of students’ prior knowledge on the subject (Driver & Oldham, 1986; Duit & Treagust, 1995). In the light of our findings, schemes SS-1 and SS-2 present such constructs regarding the sky concept. Our results suggest possible confusion arising out of the contradiction between the particular intuitive knowledge and the scientific knowledge of the subject. Since these schemes represent reasonable and plausible ideas they should not be simplified solely to the terms of right vs. wrong. Indeed, the atmosphere causes the perception of the sky (SS-I), but the sky is not a shell of air seen by the observer as it. Similarly, the sky indeed is the appearance of space around us (SS-II), but this appearance essentially depends on the atmosphere, especially during the daytime. Class discussions of the schemes, as students’ ideas, should reveal the area of their validity and thus should reduce students’ resistance to the introduction of the scientific knowledge of the subject.

In the same way, the schemes VS-1 and VS-2 may be helpful means to teach the concept of visibility distance. Vision indeed weakens with the distance (VS-I), but this is a statement of fact, and not an explanation of how it happens. The latter presents a scientific agenda. Furthermore, the attenuation of radiation intensity from a point source (inverse square law) is valid, but it does not take into account the presence of air, which is obviously important. Natural obstacles indeed may determine the area within which we see (VS-II), but this is not what limits vision in the open fields. Horizon would limit Little Prince’s vision of the objects on the surface of an asteroid or an airless planet but this is not what happens in a regular environment. It is a common experience that the sky perception depends on weather

conditions (close and spherical sky is perceived in foggy weather and extremely flatten sky in clear atmospherical conditions). These contents being discussed should precede the instruction on visibility distance as formally determined. The concept of vision depth is not intuitive, but it can be reconciled with the common sense through scientific arguments and explanation.

The perception of the flatten sky shared by the majority of the novice learners, and conflicting the spherical dome, common in most presentations of the sky, might serve an initial point of constructivist instruction of the subject.

Also, by inclusion of a well-known but very seldom-explained phenomenon of moon illusion into curriculum, one satisfies the curiosity of the learner, and enhances the knowledge with regard to the actually observed reality. This commitment is often forgotten in physics courses focused mainly on the presentation of theory.

Among beneficial teaching activities related to the topic, one can mention an observation of sky in different weather conditions, a comparative observation of night and day sky, an observation of airplanes, birds, clouds with reflection on their apparent distances and the limits of being seen, the observation of the rising (or setting) sun, moon, and familiar stars constellations (e.g., Ursae Major—Big Bear), also with regard to their apparent size compared with the same on the made photography. A thought experiment considering the shape of the sky in a hypothetical case when earth (or moon) is bigger/smaller/flat, with or without the atmosphere, can serve a context for a useful and elucidating discussion.

This study implies that the mentioned topics could be included in the curricular of science, physics, and astronomy, starting from elementary school and spirally returning to the subject in intermediate and secondary schools, and definitely, in higher education.

APPENDIX

The constructed questionnaire included several open and multiple-choice questions. We describe them here.

Q1. The question introduced two lists of terms. The first contained common scientific terms, such as force, acceleration, weight, and time. The second list included such notions as splendor, character, interest, and perception, commonly perceived as nonscientific. To learn if our subjects perceive “sky” as a scientific concept, we asked them to submit “sky” to any of the lists, and explain their choice.

Q2. The subjects were asked to describe the shape of the sky, as they perceived it. We also provided a set of profiles to facilitate the choice: (a) flat, (b) oblate, (c) spherical, (d) prolate (Figure A1).

Q3. The subjects were asked about the factors that, in their opinion, influence the shape of the sky. Parameters such as time of the day (morning/evening), weather conditions and the shape of the earth were suggested to be considered. The subjects were invited to add any other factor they thought to be relevant.

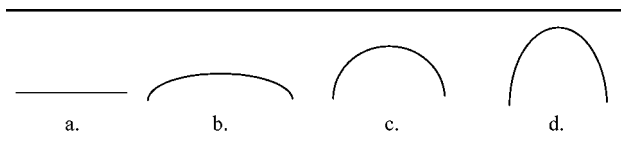


Figure A1. Profiles of the sky provided in Q2.

Q4. The subjects were asked about their assumptions regarding the shape of the “sky,” as perceived by an astronaut standing on the moon.

Q5. Students’ understanding of visibility-distance was probed. Students were asked about the factors that determine the distance limit of successful vision. The question was “Suppose on a bright day we look at a bird or airplane flying away from us. Why do we stop seeing them at some distance?”

Q6. We probed the subjects’ awareness of the apparent increase of the size of the moon and Sun when they are observed next to the horizon. To do so, three drawings, each showing two discs of the moon, near the horizon and at a higher elevation, were presented. The drawings presented views through a window and three possibilities of size perception of the moon were shown: (a) a larger disc near the horizon than in a higher elevation, (b) a larger disc at a higher elevation than next to the horizon, and (c) two discs of identical sizes regardless of the elevation above the horizon. The subjects were asked to choose the drawing, which matched their personal experience at best, and to explain their choice. They were also asked to suggest a possible experiment that can support their view.

Some variations of question Q2 were made for groups C and T. The children (Group C) were asked to draw the sky profile, as they believe it is during the daytime and at night. Only after that they were asked to choose one of the given profiles (the same given to the other subjects). On the basis of the already accumulated responses, we asked the science teachers (Group T), who were the last group of the experiment, to expand their answers to Q2 by responding to the following sub-questions:

Q2-1. What would be the shape of the sky if the earth didn’t have an atmosphere?

Q2-2. What would be the shape of the sky if the earth were a sphere of a much bigger radius?

Q2-3. What would be the shape of the sky if the earth were flat?

Q2-4. What is the shape of the sky in a country located much more to the North?

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