Children's Concepts about Weight and Free Fall

VARDA BAR, BARBARA ZINN, and RIVKA GOLDMUNTZ
The Amos de Shalit Science Teaching Centre in Israel, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

CARY SNEIDER
Lawrence Hall of Science, University of California, Berkeley, California 94720

INTRODUCTION

Many investigators have pointed out the differences between the lay and scientific interpretations of natural phenomena. Andersson (1990), in a review paper based on Piaget (1974), Minstrell (1982), and Watts (1982), sums up the contrast between the everyday concept of weight and the scientific concept. This is shown in Table 1.

Andersson (1990, p. 62) comments that this everyday thinking "is a significant feature among the pupils in the age group 11–15 years, but no systematic survey, in which written problems are given to large samples, has been carried out." He further states that these two columns "provide some clue as to the level of abstraction that pupils are required to reach before mastering the weight concept in science" (p. 62). Andersson concludes by saying that the everyday ideas show that pupils have difficulties with regard to the conservation of weight, and states that this type of conservation reasoning is not a general ability, but depends on the individual's conception of matter and weight.

Our investigation aims at finding and interpreting everyday ideas about weight as described by children of the age range 4–13 years, using quite a large sample. Other investigators in the same area either did not perform their research with participants this young (Gunstone & White, 1980, 1981; Stead & Osborne, 1981), or the age range studied was quite narrow (Rodrigues, 1980).

Science Education 78(2): 149–169 (1994)

CCC 0036-8326/94/020149-21

TABLE 1
Everyday and Scientific Concepts Concerning Weight

Everyday Concepts	Scientific Concepts
Weight is determined by the measuring method, including what one's own body feels.	Weight is established by Newton's Law of Gravitation.
The force of gravity is associated with free fall, weight with objects feeling heavy.	Weight and the force of gravity are the same thing.
The weight of an object increases with the height above ground.	The weight of an object decreases with the height above ground.
Weight depends on how objects are placed on the scales.	Weight does not depend on how objects are placed on the scales.
Weight increases if the object is compressed and decreases if it is spread out.	Weight does not depend on whether the object is compressed or spread out.
Weight disappears if the air disappears.	Weight is independent of whether there is air or not.

We believe that observing young children over a wide range of ages may provide insights into how everyday concepts develop as children mature. We will research whether or not children develop these ideas according to the "common sense theory of motion" suggested by Ogborn (1985). Notions taken from the "common sense theory of motion" that will be applied in this study are: support, heaviness and lightness, weight as a pressing force, and the need of a medium to transmit forces.

Support

In everyday life, static objects and horizontally moving objects are supported by other objects. The ultimate support is the floor or the earth. Thus, young children (aged 5–7 years) draw a horizontal line representing earth at the bottom of the page, as the ultimate support toward which things are falling (Nussbaum & Novak, 1976; Sneider & Pulos, 1983). It is suggested that viewing objects as being supported or unsupported should guide the answer to the question "why things fall?"

Heaviness and Lightness

We live in a world of objects, some of which, regarded as light, can be easily moved and lifted. Others, regarded as heavy, are difficult or impossible to lift. The concept of heaviness or lightness as a property of objects has its beginnings in these

Table 2
Common Sense Notions of Heavy and Light

Heavy Things	Light Things
Heavy things are stable and hard to lift.	Light things are not stable and are easy to lift.
Heavy things are strong. They can crush objects supporting them (Smith, Carey, & Wiser, 1985) or can break objects when falling on them (Piaget, 1972).	Light things are weak. They do not crush objects supporting them. They do not break objects when falling on them.
Heavy things exert a pressing force on supporting objects or on the hand that holds them (Minstrell, 1982).	Light things do not exert a pressing force.
Heavy things can overcome the resistance of the media. They fall through air or sink in water.	Light things cannot overcome the resistance of the media. They float in air or water.

experiences (Ruggiero et al., 1985; Watts, 1982; Andersson, 1990). Some investigators suggest that children up to the age of 9 years attribute weight only to heavy objects. Many of them regard a feather, a hair, or a dust particle as weightless (Goldmuntz, 1987). Depending on their early childhood concrete experiences with objects, common sense ideas concerning heavy and light things are characterized in Table 2.

Weight as a "pressing force"

Conceiving of weight as a pressing force or "felt weight," as described by Smith and coworkers (Smith et al., 1985), may prevent the child from realizing that an object's weight will not change if you change its shape or how you hold it. For example, imagine a flat piece of clay that we wad into a ball. People who know that weight is conserved under this circumstance, are aware that the weight will not change. The reason that young children believe that the weight increases is because the ball shape seems to "press more" than the flat shape. Likewise, if an object is held in the middle its weight is hardly felt, but when it is held at the edge it seems heavier. Even an adult who knows that weight is conserved cannot resist this perception, since a much greater force has to be applied to the object when it is held at the edge. Children who judge weight only according to the feeling of the force pressing on their hand will not be able to conserve weight under these transformations. Only a change in the child's conception of weight will enable them to understand that weight is conserved when the shape is deformed or when the object is held in a different way. This suggestion suits Piaget's (1974) later ideas. This relationship between the child's concept of weight and his ability to answer questions about what happens to the weight of an object when its shape is changed may explain Andersson's suggestion (1990, p. 63) that "conservation reasoning is related to the individual's conception of matter."

The Need of a Medium to Transmit Forces

According to previous studies (Ruggiero et al., 1985; Bar, 1989) children regard forces as acting by touch. Throughout the history of science, action at a distance has been regarded as problematic. Newton refused to explain the action of gravity. He presented no theory, only the results of previous observations and mathematical considerations. Faraday used the idea of field lines to connect the interacting objects in the electric field. It is not surprising that children may also use the idea of connection to the earth to account for why some things fall and others do not. Children consider air as the natural medium that can create the needed connection. They think that the existence of air is necessary for the action of gravity as well as for magnetic attraction. Andersson (1990) comments that this idea prevails up to at least 15 years of age.

The "common sense theory of motion" (Ogborn, 1985), as described above, can provide a framework to interpret everyday concepts about weight and free fall.

THE PRESENT INVESTIGATION

Purpose

We wanted to expand the previous research to include children from a broader range of ages, with sufficiently large sample size at each age range, to be able to draw stronger inferences about children's ideas about weight and free fall. The purposes of our investigation were:

1. To identify children's common ideas, at various age levels, concerning why things fall.
2. To determine how children's ideas about why things fall affect their predictions concerning which objects fall faster than others.
3. To correlate the development of children's conceptions of weight and free fall with their abilities to conserve the weight of deformable bodies.
4. To test the consistency of children's ideas concerning weight and free fall in different contexts.
5. To verify children's ideas about the role of the earth in the process of free fall.

Population and Sample

Over a period of 2 years and 4 months two researchers interviewed 400 children between the ages of 4 and 13. All of the children were from a kindergarten, an elementary school, and a junior high school, in a middle class neighborhood in Jerusalem. Twenty boys and 20 girls were drawn at random from the total population of each grade level. The sample represented about 30% of the total population in these schools. These children had not been formally taught about weight and free fall in school.

Testing and Scoring

Each child was interviewed for about a half hour. The same four tasks were used for all age groups. The questions were simple enough to be understood by all participants. The oral interviews were composed of four tasks, presented with demonstrations (Piaget, 1929, 1972). The four tasks were as follows:

(a) The child was shown a falling object and was asked why this object fell and why it fell downwards. Further questions inquired why the sun remains in the sky and does not fall; similarly, why the moon and the clouds remain in the sky and do not fall, and how an airplane flies without falling.
(b) The child was shown a piece of ice floating on water and plasticine sinking in it. The child was asked why the ice floats and the plasticine sinks. A further question inquired how a boat floats on water.
(c) The child was given two cubes of the same dimensions, one heavier than the other, and was asked to identify the heavier one by holding the two objects and comparing their weights. The investigators asked which cube, the heavier or the lighter one, would hit the earth first if they are dropped from the same height.
(d) The child was presented with two identical balls of plasticine and was asked whether they were of the same weight. When the child confirmed that they weighed the same, the investigator moulded one of the balls into a long snake, then into a flat "pizza," and finally into five smaller balls. After each change the child was asked if the changed balls still have the same weight and if not, which one was heavier and why.

The written protocols, which recorded participants' verbatim answers, provided the basis for the analysis. The views given by the participants of each age group were summarized. The conversation problem [task (d)] was scored as follows: a participant who gave three correct answers was considered as "conserving," one who gave one or two correct answers as "partially conserving" and one who gave no correct answers as "nonconserving." An answer was considered as correct when it was also followed by a correct justification.

RESULTS

Part I. Children's Ideas about Why Things Fall

Children's answers to tasks (a) and (b) are summarized in Figures 1–7. Participants' views concerning ice and plasticine were similar to those given in Figures 5 and 6.

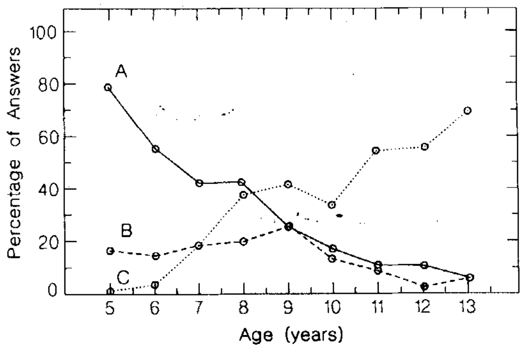

Figure 1. The reasons for free fall. (A) The object was not held. (B) The object is heavy. (C) The object is pulled by the attractive force of the earth.

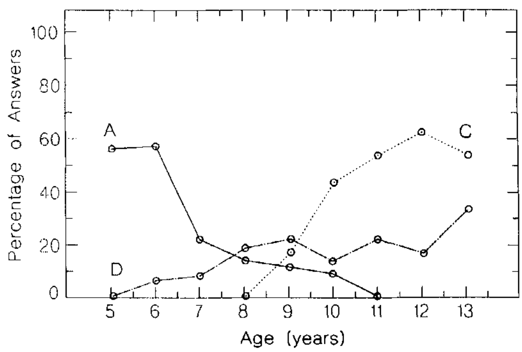

Figure 2. Why do the sun and moon not fall? (A) Sun and the moon are held or glued to the sky. (C) Sun and the moon are not influenced by the attractive force of the earth. (D) The sun and the moon are in a fixed trajectory.

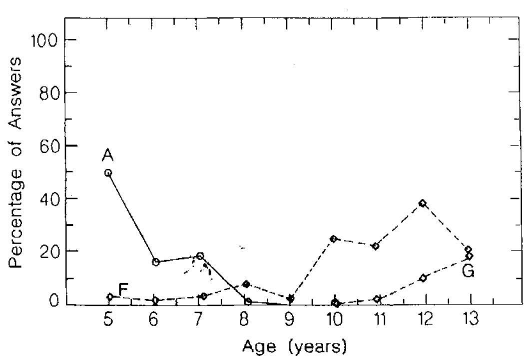

Figure 3. Why do the clouds not fall? (supported by something else). (A) Clouds glued to the sky. (F) Clouds are supported by air currents. (G) Clouds lighter than air.

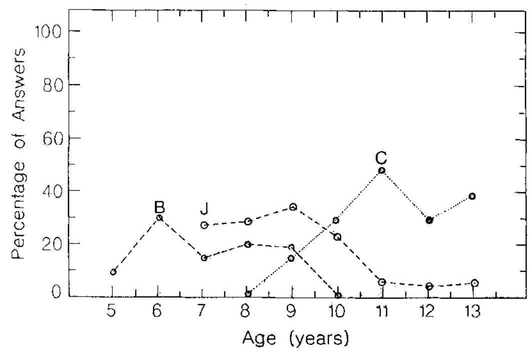

Figure 4. Why do the clouds not fall? (other reasons). (B) Clouds are light. (J) Clouds are made of vapor. (C) Clouds are beyond the earth's gravitational force.

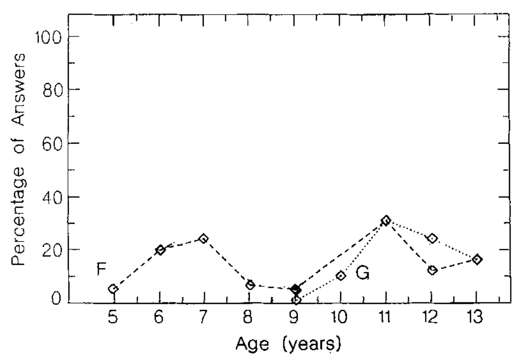

Figure 5. Why do boats float on water? (supported by something else). (F) Boats are supported by water currents. (G) Boats are lighter than water.

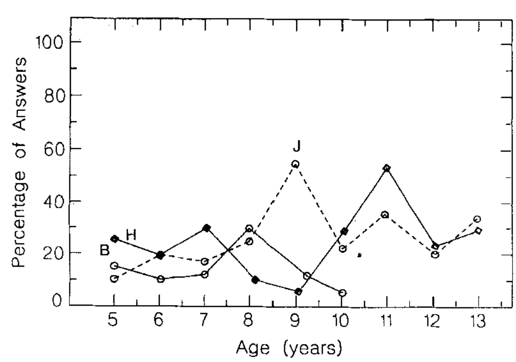

Figure 6. Why do boats float on water? (other reasons). (B) Boats are light. (J) Boats are made of wood. (H) Boats are supported by the effort of the paddles.

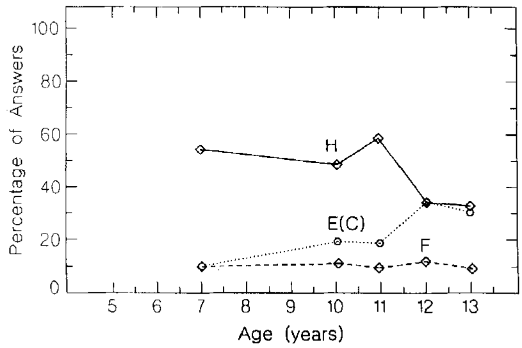

Figure 7. Why does the airplane not fall? (F) The airplane is supported by air currents. (H) The airplane is supported by the effort of the engine. [E(C)] The airplane does not fall because it has elevation force.

As seen in Figure 1, the children's answers to the question "Why do things fall?" can be classified in the following three categories.

A. Support.
B. Heaviness.
C. The earth's attractive force.

These three categories will be used to interpret the data from tasks (a) and (b).

A. Support. At all the age levels observed, many of the children's ideas could be related to the idea of support. The qualitative data collected from the children's responses was analyzed using a systemic network (Bliss et al., 1983), which is shown in Figure 8. The following analysis makes reference to this figure.

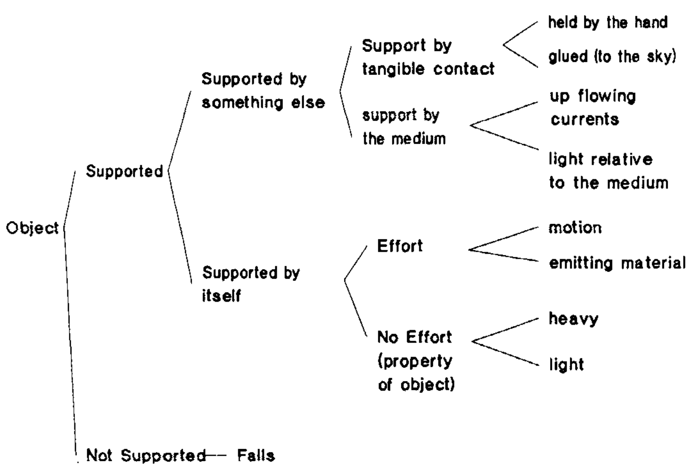

Figure 8. Children's explanations related to support.

A1. Supported by something else. When an object is kept from falling by something else, some students named a tangible support, while others referred to the medium as the means of support.

Support by tangible contact. The most common views among children of ages 5–7 years in response to the first task is that objects fall if they are not supported by something tangible such as a hand or a table. This view is consistent with what they see everyday. Pupils thus concluded that the usual behavior of objects is falling:

> *An object will fall when it reaches the edge of something.*
>
> *Objects fall because they are not held* (Fig. 1, curve A).

Our inference that the youngest students believed that a tangible support was necessary to keep an object from falling was reinforced by the most common answers among this age range to the questions which inquired why the sun, moon, and clouds remain in the sky and do not fall:

> *The sun and the moon do not fall because they are glued to the sky* (Fig. 2, curve A).
>
> *The clouds do not fall since they are glued to the sky* (Fig. 3, curve A).
>
> *The sun and the moon do not fall since they are held in a solid track* (Fig. 2, curve D). This view resembles the biblical "Song of Deborah" which refers to the "stars in their tracks."

These views are characteristic of the "common sense theory of free fall" (Whitelock, 1991), which states that things fall unless they are "supported."

Support by the medium. Older children, aged 9–13 years, who referred to support, gave a more sophisticated view. They suggested support by the medium. One group indicated that things would be supported by upflowing currents. For example:

> *Boats are supported by water currents* (Fig. 3, curve F).
>
> *Clouds are supported by air currents* (Fig. 5, curve F).
>
> *Aeroplanes are supported by air currents* (Fig. 7, curve F).

Other students who suggested support by the medium explained that objects float because they are lighter than the surrounding medium. Clouds are sometimes described as light relative to air, and boats as light relative to water. These floating objects are described as light relative to the whole amount of the fluid. (The percentages of students who gave these kinds of answers are shown in Fig. 3, curve G, Fig. 5, curve G). Only five participants tried to compare equal volumes: *"If the air were as big as a cloud, it would be heavier."*

A2. Supported by itself. Some students indicated that they believed that an object could support itself. We could distinguish two versions of these ideas. Objects can be supported by their own efforts, or just because they are heavy or light.

Objects supported by their own efforts. Some students who believed that objects can be supported by their own efforts referred to motion. For example:

> *Birds flap their wings and do not fall* (while not discussed in the interview, this is a view heard in our classes).

Boats do not sink because people row them (Fig. 6, curve H).

Aeroplanes do not fall because they have engines (that move them) (Fig. 7, curve H).

Other students referred to some material that is emitted from the object as a means of support. For example:

The clouds do not fall because they make wind (one 8-year-old and one 7-year-old).

The sun is supported by its own fires (one 9-year-old respondent).

Objects supported as a result of a property of those objects. Some children said that an object can support itself because it is heavy. For example:

The clouds are heavy and strong thus they can hold themselves (about 5% of the views of the age range 5–7 years, not recorded in Fig. 3).

The ice floats on water because it is heavy.

Boats float because they are heavy (Piaget, 1972).

These participants believe that heaviness implies both stability and strength, when a heavy object is strong enough to hold itself and not fall. As pointed out in the introduction, this view is one common sense notion of weight. Additionally, this view is not consistent, since some students in the age range of 5–7 years expressed the opposite view:

The clouds do not fall because they are light (Fig. 4, curve B).

The ice floats on water because it is light. But: "*The plasticine sinks because it is heavy and strong* (about 80% of all participants).

These participants think that light things are weak (cannot penetrate the medium), while heavy things are strong and overcome the resistance of the medium. Thus the idea of support, or lack of it, changes its meaning with age; but all the responses given above relate to support in one way or another (Fig. 8).

B. Heaviness. About 20% of the 5–10-year-olds said that things fell because they are heavy. This idea appears also at older ages but less frequently (Fig. 1, curve B). What distinguishes the younger and older students is their explanations for *why* heavy things fall, and light things do not fall. Five- to 7-year-olds usually explain that light objects do not fall because they are too weak to penetrate the medium: "*they don't have enough force.*" In contrast, the 7–9-year-olds tend to explain lightness in terms of an absence of heaviness. Things that have the property of heaviness fall, and those that don't have this property do not fall. For example:

Clouds are light and not heavy and do not fall (an 8-year-old, Fig. 4, curve B).

Boats float because they are light (Fig. 6, curve B).

Many older children, around age 9, relate lightness or heaviness of an object to the material from which it is made:

Clouds are made of vapour (Fig. 4, curve J).

Boats are made of wood (Fig. 6, curve J).

Ice is made of water.

These students refer to the light materials of which the objects are made as a way of justifying why they do not fall or sink.

C. The Earth's Attractive Force. Most of the 9–13-year-olds answered the question "Why do things fall?" with the Hebrew response, *"Koach meshichat hadama,"* which is best translated *"the earth's attractive force"* (Fig. 1, curve C). A follow-up study that will be briefly described in the Conclusions of this article, found that in the United States, children in this age range frequently used the term *"gravity"* in response to these questions. When asked what they mean by the word gravity, the most frequent answer was *"the force that keeps us on earth,"* others defined it as *"the force that keeps us down."*

Children in this age range (9–13) also say that the sun, the moon, and the clouds do not fall because they are beyond the reach of the earth's attracting force (Fig. 2, curve C and Fig. 4, curve C). These answers are related to the idea that a medium is needed to transmit forces. Many children suggested that the absence of air near the sun explains why it is beyond the reach of the earth's attractive force.

As for airplanes, participants suggested an elevation force which can counteract the earth's attracting force and thus prevent them from falling [Fig. 7, curve E(C)].

Some of the older students (age range 9–13 years) replied that the sun was far away from the earth, beyond its attractive force, *"in a far away trajectory."* (The Hebrew word *maslul,* which these students used, may be translated as track or trajectory.)

It is interesting to find that the idea that things fall unless they are supported still exists among 9–13-year-olds, but accompanied by an explanation related to a "reversed" earth's attractive force. Some children say that things fall *"because there is not enough gravity to hold them."* We interpret this to mean that things fall unless they are supported, and that gravity is the force that provides the support.

Part II. Children's Predictions about Falling Objects

Figure 9 summarizes children's answers to task (c), in which they are given two objects of the same size but different weights and are asked which would hit the ground first if dropped.

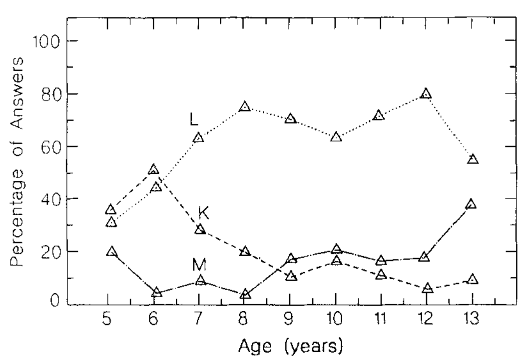

Figure 9. Which object will hit the earth first: (K) The light object. (L) The heavy object. (M) The light and the heavy objects will reach the earth together.

Some young children (4–5-year-olds) say that the heavy object and the light object will hit the floor at the same time. These children do not consider the relative weights of the objects to be a relevant variable.

At ages 5–7 about 50% of the children say that the light object will precede the heavy object, a view also recorded by Piaget (1972). They explain that the light object is faster than the heavy object based on their own experiences in throwing things.

Starting from age 7, when heaviness and the earth's attracting force are considered reasons for falling, most of the participants say that the heavy object will hit the ground first. They justify this by saying that heaviness is the reason for falling; thus the heavier object should precede the lighter one.

At age 13 years, a considerable number of participants say that the two objects will hit the floor together, basing their answers on experience or on their reading of Galileo's experiments. Even these answers do not reflect a newtonian view as they are not based on Newton's second law. Some said that *"the same force is acting on the objects,"* thus a wrong explanation leads to the right prediction. The same prediction and explanation was also recorded by Brown and Clement (1992) at the high school level. The answer that the heavy object would hit the ground first, is given by many adults and university students not majoring in science according to our anecdotal observations.

Part III. Conservation of Weight of Deformable Bodies (Plasticine)

Children's answers to task (d) about the conservation of weight of flexible bodies (plasticine) are given in Figure 10. In this task students were asked what happens to the weight of a lump of plasticine when the form is changed.

At 5 years of age, most of the children do not conserve weight in this situation, while at age 6 years only 40% do so. Between the ages of 7 and 9, 75% of the participants conserved weight when the plasticine was deformed. From age 9 on, 90% could be considered as conservers. We will discuss the relationship between the ability to conserve weight of deformable bodies and students' ideas about free fall in the Discussion section.

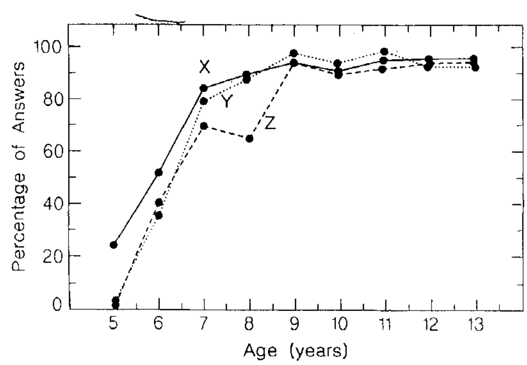

Figure 10. The conservation of weight using plasticine. (X) The ball was divided into smaller balls. (Y) The ball was changed into a flat "pizza." (Z) The ball was changed into a long "snake."

DISCUSSION

Are Children's Explanations about Weight and Free Fall Consistent?

Researchers have found that the context and setting of a task can influence a child's performance (Wason, 1977; Donaldson, 1978; Bar, 1987; Stavy, 1990). Such inconsistant behavior has been interpreted by researchers in different ways. Driver (1978) has interpreted the inconsistency in thinking skills from task to task as an argument against the existence of piagetian stages. McCloskey (1983) has claimed that seemingly inconsistent performances may reflect certain underlying "modes of thinking" that are consistent within the child, but that result in different performances evoked by different tasks (McCloskey, 1983; Carey, 1986). Still another view is expressed by Clough and Driver (1986) who suggest that some concepts are consistent over tasks, but other concepts are task dependent.

In our view, these different interpretations say more about the expectations of the researchers than about the ideas of children. After all, a set of tasks that researchers believe require the same knowledge and skills to answer successfully, may be perceived quite differently by children. It does not necessarily imply that the children are being inconsistent; but only that their answers appear inconsistent from the researcher's point of view.

Our study included several tasks designed to elicit children's ideas about why things do or do not fall. As a first approximation, many of their answers to these questions appeared to be task dependent. For example, the children were asked why clouds and airplanes do not fall. Among the 13-year-olds, the most common answers were that clouds do not fall because they are beyond earth's force of attraction (40%); while an airplane does not fall because it is supported by the force of its engine (35%).

We believe that it would be a mistake to conclude from this data that students' ideas are inconsistent. If we apply Whitelock's common sense theoretical model (1991), we can see a common thread in the child's thought that might not otherwise be apparent. Most students of this age are aware of the earth's attracting force as being the primary reason that things fall (70% of 13-year-olds). Even though it is incorrect to say that clouds are beyond the earth's force of attraction, that view is consistent with the child's common sense theory. Likewise, a child who believes that the earth's attraction causes things to fall must look for an opposing force; and the most obvious is the effort of an airplane's engine. Consequently, in the following discussion we shall consider Whitelock's common sense model in interpreting the students' answers to our questions.

We will also look for common age differences. For example, at 4–5 years of age, some of the children's answers reflected animist or teleological thinking. The students say that things fall because they have to, the sun and moon do not fall because they have to give light, the clouds do not fall because they have to give rain. It is not claimed that they are in a "stage" of this kind of thinking since many of these same children gave physical explanations for the floating of boats, such as that boats float due to water currents.

Finally, we shall look for relationships between different domains of knowledge at different age levels. For example, the explanation that boats are held by water currents was recorded for all age groups. (Fig. 5, curve F). With regard to the clouds, this same explanation was usually given by students aged 10 and older (Fig. 3, curve F). One explanation for this age difference is that many of the younger children do not usually perceive unmoving air as existing matter (Bar & Travis, 1991; Bar & Galili, 1993). Since respondents of this kind are at most 40% of the sample, some older children may also not perceive air as matter (Stavy, 1990).

While these task-dependent differences in the students' answers exist, they can be related to each other by using the "common sense theory," in light of age differences and relationships to other domains of knowledge.

An Interpretation According to the Common Sense Theory

At the age range 5–7 years, the participants' answers followed the pattern of Whitelock's common sense theoretical model (1991), that falling is the natural motion, while preventing something from falling needs effort. Most of the participants related this effort to a tangible connection: objects do not fall when held (Fig. 1, curve A), or when they are set on a supporting object, or glued to the sky (Fig. 2, curve A and Fig. 3, curve A), or when attached to a fixed track (Fig. 2, curve D). For these young children the sky is a real solid cover. These views only rarely appeared in older participants. This might explain why other researchers (Sneider & Pulos, 1983) have observed that some young children believe that the earth is composed of two hemispheres: a lower hemisphere which is made of dirt and rocks, and an upper hemisphere which is composed of the sky, enclosing the flat part in the middle where people live.

Other participants of this same age range said that things do not fall either because they are heavy (clouds and boats) or because they are light (Fig. 4, curve B and Fig. 6, curve B). The first kind of answer relates heaviness with the properties of stability and strength as in "*The clouds are heavy and strong and can hold themselves.*" The same idea appears also in Piaget (1972) regarding boats. Boats are thought to be able to float because they are "heavy," where heavy means that the boats have the strength to keep themselves up. The second kind of answer emphasizes only the connection between being heavy and being strong when the light object is described as too weak to penetrate, fall or sink, and remains suspended or floating.

These seemingly contradictory answers identify weight with force—the force to crash, the force to penetrate, the force pressing on one's hand, and the inner "force" that can keep something stable. Smith and coworkers (1985) also recognized the same idea about weight, calling it "felt weight." The definition of weight as "felt weight" is not restricted only to this age range. Vestiges of this view appear also in 11–15-year-olds as reported by Andersson (1990, p. 63): "Weight is determined by the measuring method including *what one's own body feels* and weight is associated with *objects feeling heavy.*"

At age range 7–9 years, a profound change has occurred in children's conceptions of weight, as 75% of the children have come to understand that the weight of a piece of plasticine does not change when it is deformed (Fig. 10). Following Piaget (1974), Andersson (1990), and Slone and Bokhurst (1992) who suggest that being able to conserve an amount reflects a change in its conception, we assume that these children do not relate weight only to the perception of force pressing on the hand. But they might recognize that "heaviness" is a measure of the amount of matter contained in the object, and is related to the properties of the material from which the object is made. (The child's changing conception of weight will be discussed in a broader context later, under the heading "Is the explanation of free fall related to the child's concept of weight?") Children's classification of materials into heavy and light, those that sink and those that float in air and water, appears also in Andersson (1990) and resembles Piaget's (1972) findings about 8-year-olds' definition of heavy objects as made of "condensed matter."

Growing experience at this age level shows that some things fall very slowly: a feather, a hair, and dust. Thus the child adds to the explanation of falling, some inner property of the objects—their weight. Weight is no longer identified only with the concrete perception of force exerted on the hand, but as the property of objects containing a large amount of matter: *"weight is how much it contains . . ."* as one of the participants put it. Heavy things are described as "a fat man" or "a book with many pages" and a lack of support triggers falling for those objects which are heavy. This change in the child's concept of weight is thus connected to a change in the explanation for free fall (compare Figs. 1 and 10). With a changing conception of weight comes the recognition of "heaviness" as a reason for falling. For the child of this age, heavy objects fall while light objects do not fall.

How does the idea of heaviness as a reason for falling relate to the children's previous idea that "Things fall because they are not held?" We suggest that the child still thinks that the object falls when not held, since the "support" explanations of not falling prevail at the age range 7–9 years, and even at some older ages. However, the notion of support has become more sophisticated. A deeper unseen reason for falling is added—the concept of heaviness. The common sense model of "falling unless supported" still holds, but it has now come to mean that "only heavy objects fall if they are not supported."

The child's estimation of the time span of falling things changes also (Fig. 9). Starting from age 7, children say that when objects are dropped heavy objects precede light ones, "since heaviness is the reason for falling."

At the age range 9–13 years the attractive force of the earth is given as the reason for falling by most of the children. But from the students' answers to all of the questions we can infer that they see the earth's attractive force as acting on an object's weight, thus causing the object to fall. Support for this idea comes from a follow-up study (Bar et al., 1993) in the United States, in which we asked children to imagine a weightless object, and to say whether or not it would fall. A typical answer was, *"It won't fall because there is no weight for the gravity to pull."*

Additionally, "support" explanations are still given by children at this age, as in the form of supportive water currents and air currents. So, we can say that the same common sense model of "falling unless supported" describes children's thinking even at this age, but it is more elaborate than at younger ages. For the majority of 9–13-year-olds, the earth's attractive force acts on an object's weight. The object will fall if it is heavy. A heavy object will fall if it is not supported. The same ideas also appear among older ages according to Andersson (1990).

The new idea that appears at age range 9–13 is that some objects do not fall because they are far away from the earth and are not affected by its force of attraction. Some children explain this by saying that the sun and moon are outside of the earth's atmosphere: *"The atmosphere is like a top,"* or *"an invisible ball which keeps everything inside of it,"* and *"gravity does not affect the moon because there is no air there."* Others say that the sun and moon are very far away and moving in some remote trajectory or track, disconnected from the earth and not affected by its force of attraction. These views probably have their source in the common sense theory that force acts through touch, and a connection is needed for the operation of forces at a distance.

A few alternative ideas that we have observed at this age level also relate the ideas of falling, gravity, and support, but in different ways. Some children invented a kind of "reverse gravity." For example: *"Things fall because there is not enough gravity to hold them."* Another student said that *"Gravity is the force that exists in space and holds things from falling."* One girl invented a theory of gravity which resembles the ideas of Aristotle. She said that near the earth there is air that keeps everything down, while in space there is another kind of matter she called "helium," which keeps things from falling. All these ideas show that the notion of falling unless supported still exists in this age range.

The children's reasoning becomes gradually more abstract: tangible connection at ages 5–7 years, heaviness as a property of the object at ages 7–9 years, and the attractive force of the earth at ages 9–13 years.

Is the Explanation of Free Fall Related to the Child's Concept of Weight?

As described above, children older than 9 years old are able to recognize that a deformable solid retains (conserves) its weight when its shape is changed at about the same age as they change their reasoning about why things fall (compare Figs. 1, 2, 3, and 4 with Fig. 10, focusing on the changes that occur starting at about age 8). This is also the age when the majority of the children say that the heavy object precedes the light one (compare Fig. 9 and Fig. 10, starting at about ages 7 and 8). Is this correlation only coincidental or is there some explanation that can account for it?

Attributing this relation to the artificial effect that both the development of the concept of free fall and the development of the ability to conserve weight are age dependent is unacceptable, because the change from nonconservation to conservation occurs within a relatively short age range (Fig. 10). In his earlier works, Piaget claimed that conservation is a result of the ability to make use of reversibility and compensation operations (Flavell, 1963). This cannot be the only reason, since children conserve numbers from the age of 5, conserve amounts of water from age 6 or 7, and start to conserve weight only from ages 7–9.

We agree with Andersson (1990) that the ability to conserve a given quantity is also related to the way this quantity is conceptualized. Concerning weight, the justifications of both conserving and nonconserving participants provide insight. Most of the nonconserving children (89%) said that the ball is heavier than the long "snake," the flat "pizza," or the group of five balls into which it had been divided because *"the ball presses the hand harder."* This view resembles their explanation about floating: *"Too weak to penetrate,"* and about sinking *"heavy, strong and sinks."* Rowell and Dawson (1977) describe in detail a case of a pupil whose conception of weight was "pressing force" and indeed this pupil did not conserve weight. In our follow-up study in the United States, we also came across one 11-year-old child who said that *"weight is the force pressing on the scale"* and at the same time said that *"things fall when they are not held."* This child also did not conserve weight. Children who conserved weight, on the other hand, spoke about both the ball and the deformed ball as containing the same amount of plasticine and thus having the same weight. While not technically correct, as we discuss below, it appears that conceptualizing weight as the amount of matter helps children understand the conservation of weight. This same conception can account for the change in the explanation given for falling, suspension, and floating as well as for the prediction that the heavier body will hit the earth before the lighter one.

The Development of Children's Ideas

Young children, 5–7-year-olds, define weight as *"pressing force"* or *"a force to overcome resistance."* Older participants define weight as the amount of matter, roughly similar to mass. The latter definition is more advanced since it helps the child understand that the weight of deformable bodies is conserved. The definition of weight as "how much matter it holds" (Ruggiero et al., 1985; Watts, 1982; Stead & Osborne, 1981) relates weight to mass, but not to the force due to gravity. Thus it does not coincide with Newton's formalism. This was also clear from our observation that none of our participants could explain correctly why both the light and the heavy object should reach the ground together. Thus, children progress in their understandings by passing through a series of intermediate notions which, though incorrect from a scientific point of view, reflect progress in children's understanding (Baxter, 1990).

Different conceptions of weight appeared also in the scientific arguments in Galileo's time (Drake, 1980). The idea that objects should overcome water resistance in order to sink is attributed to Aristotle. Galileo argued this point and claimed that floating and sinking are related to the object's weight, and not to its form (Drake, 1980). "Aristotle says that if the *power* of the *heaviness* exceeds the resistance of the medium the body will descend, if not it will float. I [Galileo] say that it is the *heaviness* of the body and the *heaviness* of the medium that must be compared." Children of age range 9–13 years are closer to Galileo's concept. Children's ideas do not, however, exactly reflect the ideas that were historically held. They do not have the complete picture of the four elements of Aristotle, each keeping in its place. Young children, ages 5–7, believe that even the stars will fall unless they are glued to the sky or located beyond the earth's gravitational attraction. They also explain that clouds stay aloft because they are made of vapor, a weightless material, or that they are supported by air and not because they are made of matter whose place is above the earth.

Children's Ideas about Gravity and Cosmology

Comparing our findings to those that Piaget observed before 1929, we see that the idea of the earth's attractive force (in Israel) or of gravity (in the United States), so popular among our pupils (Figs. 1, 2, and 3), was not recorded by Piaget. This can be attributed to the growing awareness of the concept of gravity, since Piaget's work was done over 60 years ago. Being acquainted with "space," American subjects use the word gravity very naturally, whereas the subjects observed by Piaget did not. Israeli subjects spoke about the force of attraction of the earth. But what do children mean by gravity? Inferred from their answers, "gravity" is the force which keeps everything down, or causes things to fall to the earth. This force is limited as it acts only on the objects that are within its reach (Stead & Osborne, 1981; Watts, 1982) and is related to the existence of air. In spite of the lip service to gravity, most students' cosmology remains earth-centered. The earth is the center of the world, the sun and the moon move in a remote trajectory far beyond the reach of the earth's gravitational force. Thus, 400 years after Galileo, 13-year-olds in Israel still hold earth-centered views concerning gravity. This is similar to McCloskey's claim (1983) that even university students have pre-Galilean mechanical views, which stresses the role of common sense.

CONCLUSIONS

At the beginning of this article we referred to Andersson's (1990) comment that everyday thinking is a significant feature among the pupils in the age group 11–15 years; but no systematic survey, in which written problems are given to large samples, has been carried out. The study reported here supports and considerably expands the scope of Andersson's work. Rather than using written questionnaires, we have conducted in-depth half-hour interviews with 400 students, requiring 2 years and 6 months of effort. The age range covered by our study, 4–13-year-olds, overlaps the lower age range of Andersson's sample.

We have confirmed that children's ideas can be interpreted in terms of a meaningful common sense theory. As young children observe in the world around them, things fall because they are not supported. As they mature, this idea remains, while it becomes elaborated first by the idea of heaviness at ages 7–9, and later by the idea of the earth's attractive force during the ages 9–13. Thus we have found that, although the basic common sense model remains, its appearance changes with age.

Understanding how children's conceptions of matter change with age has value in and of itself. Such work provides insights into how human beings acquire knowledge, as well as into the nature of the concepts themselves, as we have seen in the Discussion section. Additionally, our work has practical applications in the classroom by identifying misconceptions that can be treated by instruction. We explored such an application during a pilot study in the town of Albany, California, with the assistance of sixth-grade teacher, Phoebe Tanner, and two classes of sixth graders, who were approximately 12 years of age. The remainder of this article will briefly report on that study, as it provides a graphic example of how these results can be applied in the classroom.

First, research in this field has pinpointed the middle school as the ideal age of intervention. As our research in Israel has shown, children gradually develop an understanding of why things fall through normal experiences with the world. By the time they reach age 13, they understand that gravity acts on heavy objects to pull them down, and that a heavy object will fall unless it is supported. But research by Andersson (1990), Sequiera and Leite (1991), and Brown and Clement (1992) indicate that unless they have received effective instruction, people's explanations for why things fall will change very little from a typical 13-year-olds' explanation. Middle school is the first time that children's conceptions of gravity, weight, and free fall have become consolidated. They are ready for the next step. And, they tend to be interested in space and astronomy, so they have the motivation to go further.

In California we conducted interviews and written pretests with two classes of students. Our sample comprised 48 students. The treatment was a 90-minute class, which began with discusison of how a ball would travel as it rolled off a table. The students predicted the trajectory of the ball when it was rolled slowly, and then quickly, and debated their various predictions. Then, they experimented with rolling balls in small groups and discussed their results. They had no difficulty identifying the typical path of a trajector, with the teacher acting only as a facilitator.

Next, the teacher presented a short lesson using transparencies and a Socratic dialogue approach to build on the students' understanding of a trajectory and show how a baseball might achieve orbit if it is hit hard enough. The students had no difficulty recognizing that gravity would pull the baseball into orbit around the earth. Then they considered the space shuttle, and finally the moon, recognizing that here, too, gravity must act to pull the object into orbit around the earth. At that point we confronted the students with the seeming contradiction that the space shuttle and moon were held in orbit by gravity—but there is no air in space! After some discussion, and help from the teacher, the students recognized that the best way out of the dilemma is to suppose that gravity can act beyond earth's atmosphere. We then discussed how that applied to Jupiter's moons, which the students had been studying previously, and to all of the planets in the solar system.

The results of the written tests and interviews showed that prior to the lesson 65% of the students believed that it was necessary to have air in order to have gravity to act. After the lesson only 20% of the students believed that this was so. However, some of the students who had previously believed that gravity cannot act beyond the earth's atmosphere changed their minds to gravity acts *"only a little"* in space, or *"just near planets like Jupiter."* These results are consistent with Brown and Clement's (1992) finding that even high school students' concepts about matter, gravity, and why things fall are not easy to change. Still, it is worth the effort since such instruction appears to be the only way that we can help people develop beyond the conception of a typical 13-year-old that gravity is "something that keeps things down," to "a force that holds the entire universe together."

REFERENCES

Andersson, B. (1990). Pupils' conceptions of matter and its transformation (age 12–16). *Studies in Science Education, 18,* 58–85.
Bar, V. (1987). Comparison of the development of ratio concepts in two domains. *Science Education, 71*(4), 599–613.
Bar, V. (1989). Introducing mechanics at elementary school. *Physics Education, 24*(6), 349–352.
Bar V., & Travis, A. S. (1991). Children's views concerning phase changes. *Journal of Research in Science Teaching, 28*(4), 353–362.
Bar, V., & Galili, I. (in press). The development of the conception of evaporation. *International Journal of Science Education.*
Bar, V., Sneider, C., & Martimbeau, N. (in press). Does gravity need air? *Learning.*
Baxter, Y. (1990). Children's understanding of familiar astronomical events. *International Journal of Science Education, 12*(5), 502–513.
Bliss, J., Monk, M. & Ogborn, J. (1989). *Qualitative data analysis for educational research.* London, Croom Helm.
Brown, D., & Clement, J. (1992). Classroom teaching experiments in mechanics. In R. Duit, F. Goldberg, & H. Neidderer (Eds)., *Proceedings of the international workshop on research in physics learning: Theoretical issues and empirical studies.* Bremen, Germany: IPN, pp. 380–389.
Carey, S. (1986). Cognitive science and science education. *American Psychologist, 41*(10), 1123–1130.
Clough, E. E., & Driver, R. (1986). A study of consistency in the use of students' conceptual framework across different task contexts: *Science Education, 70*(4), 473–496.
Drake, S. (1980). *Galileo.* Oxford: Oxford University Press.
Driver, R. (1978). When a stage is not a stage. *Educational Research, 21*(1), 54–61.
Donaldson, M. (1978). *Children's minds.* London: Fontana Collins Press.
Flavell, J. H. (1963). *The developmental psychology of Jean Piaget.* New York: Van Nostrand.
Goldmuntz, R. (1987). Children's explanations concerning weight and free fall (in Hebrew). Master's thesis, The Hebrew University of Jerusalem.
Gunstone, R. F., & White, R. T. (1980). A matter of gravity. *Research in Science Education, 10,* 35–44.
Gunstone, R. F., & White, R. T. (1981). Understanding gravity. *Science Education, 65*(3), 294–299.
McCloskey, M. (1983). Intuitive physics. *Scientific American,* 114–122.
Minstrell, J. (1982). Conceptual development in the natural setting of a secondary school science classroom. Mercer Island High School, Washington. *Education for the 80's: Science.* Washington, DC: National Education Association.
Nussbaum, J., & Novak, J. D. (1976). An assessment of children's concepts of the earth utilizing structured interviews. *Science Education, 60*(4), 535–550.
Ogborn, J. (1985). Understanding students' understanding: An example from dynamics. *European Journal of Science Education, 7*(2), 141–150.
Piaget, J. (1929). *The child's conception of the world.* New York: Harcourt Brace.
Piaget, J. (1972). *The child's conception of physical causality.* London: Routledge and Kegan.
Piaget, J. (1974). *Understanding causality.* New York: Norton.
Rodrigues, V. P. (1980). Notions of physical law in childhood. *Science Education, 64*(1), 59–84.

Rowell, J. A., & Dawson, C. J. (1977). Teaching about floating and sinking: further studies towards closing the gap between cognitive psychology and class-room practice. *Science Education, 61*(4), 527–540.

Ruggiero, S., Cartelli, A., Dupre, F., & Vincentini Missoni, M. (1985). Weight, gravity and air pressure: Mental representations by Italian middle school pupils. *European Journal of Science Education, 7*(12), 181–194.

Sequiera, M., & Leite, L. (1991). Alternative conceptions and history of science in physics teacher education. *Science Education, 75*(1), 45–56.

Slone, M., & Bokhurst, F D. (1992). Children's understanding of sugar water solutions. *International Journal of Science Education, 14*(2), 221–235.

Smith, C., Carey, S., & Wiser, M. (1985). On differentiation: A case study of the development of the concepts of size, weight and density. *Cognition, 21,* 177–237.

Sneider, C., & Pulos, S. (1983). Children's cosmographies. Understanding the earth's shape and gravity. *Science Education, 67*(2), 205–222.

Stavy, R. (1990). Children's conceptions of change in the state of liquid (and solid) to gas. *Journal of Research in Science Teaching, 27*(3), 247–266.

Stead, K., & Osborne, R. (1981). What is gravity? Some children's ideas. *New Zealand Science Teacher, 30,* 5–12.

Wason, P. C. (1977). The theory of formal operation—a critique. In B. A. Gerber (Ed.), *Piaget and knowing.* London: Routledge.

Watts, D. M. (1982). Gravity—Don't take it for granted! *Physics Education, 17*(4), 116–121.

Whitelock, D. (1991). Investigating a model of commonsense thinking about causes of motion with 7–16 year old pupils. *International Journal of Science Education, 13*(3), 321–340.

Accepted for publication 11 May 1993