Students’ Operations with the Weight Concept

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This study analyzes the operational knowledge of the weight concept of high school students after two educational levels: Introductory and advanced physics courses. The results show that most of the students at both levels construct alternative understanding of weight, which can be represented in operational schemes. The study shows that apparent and true weight concepts are poorly assimilated by most of the advanced placement students. Students’ confusion is interpreted as reflecting the misfit of the weight concept image by students and the weight concept definition currently adopted by most of U.S. physics textbooks and identifying weight with the gravitational force. The origins of the shortcomings of the alternative knowledge about weight are listed and discussed. An alternative, operational definition of weight, separating it from the gravitational action at a distance, might be preferable in the educational context. Students’ intuitive weight considerations have close historical parallels, which could elucidate the epistemological roots of their alternative knowledge.

INTRODUCTION

Learning and teaching are related multidimensional processes of an extremely complicated nature, both of which are far from being fully explored (Niedderer & Schecker, 1992). The constructivist approach to teaching science recognizes this complexity and elaborates on students’ active roles in these interactive processes (von Glaserfeld, 1989, 1992). Common in recently discussed learning theories is the recognition of the interaction between initial and newly acquired knowledge schemata, causing complex structural transformations of the learner’s knowledge.
Some researchers emphasize the reorganization of preinstructional knowledge via spontaneously constructed cognitive units, or “facets” (Mistrell, 1992). Others emphasize the integration of naive knowledge with formal scientific ideas (Grayson, 1993), proposing to facilitate the latter’s evolution through the use of anchoring analogies (Clement et al., 1987). A more radical approach describes conceptual change as a type of phase transition or “conceptual exchange.” This approach analyzes the conceptual tension between the student’s knowledge and a taught scientific idea and the resolution of the conflict in a newly constructed schema (Hewson, 1981), whether built through unfruitful attempts or “fumbling about” (Posner et al., 1982), or through a well-defined series of stages (Dykstra, 1992). McCloskey (1983) speculates about the spontaneous development of students’ beliefs toward a mental model based on their intuitive, everyday experience. diSessa proposes (1983, 1990) to look far back into the mind’s mental history at the formation of an individual’s most basic rules of thinking, p-prims. He sees them as guiding constraints of the individual’s cognitive activity. It is seemingly impossible to describe by a simple linear model how the process of learning goes as a broad range of factors, varying in different individuals, and depending on scientific contexts and learning goals has to be included. Despite this complexity, the educational process should not be difficult to describe holistically (Fig. 1). It is quite indisputable that among natural measures of success in the learning process is a “FIT” (Fig. 1) between the newly acquired knowledge and the commonly adopted scientific knowledge.

![Diagram](image)

**Figure 1.** An overview of the educational process. “Educational resource” might include: instructor, textbook, computer tutorial, etc., and is supposed to be shaped according to the accumulated “pedagogical knowledge,” as well as provide contents of the “formal science knowledge.”
This fit could be reliably evaluated by investigating students' operational knowledge, which often reveals a conceptual mismatch between actually acquired and formal knowledge despite satisfactory declarative knowledge. Therefore, investigation of students' operational knowledge, its content and organization, was the subject of this study.

A series of factors was established as essential in determining results of learning (Duit et al., 1992). We consider here factors of a different type. Suppose that formal knowledge allows more than one way to describe a certain physical phenomena or to define a particular physical concept. It is natural to assume that among the factors to guide a science educator is the “DISTANCE” (Fig. 1) between students' original knowledge and the formally presented dogma. From this perspective, students' knowledge in the domain should be considered. This analysis might also elucidate origins of some commonly observed misconceptions.

STUDY SUBJECT AND GOALS

The concepts of weight and gravitational force provide an illustrative example of the case just mentioned. Though no research has focused on the differentiation between them, the complexity and problematic nature of children's views on gravity and weight were documented over the whole spectrum of students' ages, from elementary school (Nussbaum & Novak, 1976), through intermediate–high school, to college–university students (Gunstone & White, 1980, 1981) and school teachers (Kruger et al., 1990). Watts (1982) described students' knowledge about weight and gravitation in terms of eight possible frameworks. Regarding the leading science curricula in England, he stated that the relationship between gravity and weight is not always made clear. The numerous difficulties students have in constructing knowledge in this domain should be considered against the background of the dichotomy in the weight definition (Galili, 1993). The majority (though not all) of science textbooks define “weight” as a synonym for the gravitational force exerted on the body by the Earth:

We shall use the symbol \( F_{\text{grav}} \) when the particular force involved is the gravitational pull to the Earth. Because this case is so frequently considered, a special name for \( F_{\text{grav}} \), namely weight, and a special symbol, \( W \), is generally used. (Holton, 1956, p. 64)

At the advanced level, however, this presentation is usually followed by the separation between the true (the gravitational force itself) and apparent (the result of measurement) weights (Halliday et al., 1993), both applied on the body.

Alternatively, weight is defined as the force exerted against the support. It has been adopted by far fewer investigators (Chaikin, 1963; French, 1971; Marion & Hornyack, 1982). Some investigators use a practically equivalent definition (Keller et al., 1993). In short, we will distinguish only between two major approaches, approach I (or definition I) and approach II (or definition II) (Table 1).

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1Our research effort covered mainly textbooks in English published in the U.S.

2It is important to note that these authors refer to the decision of the General Conference on Weights and Measures (CGPM) (Keller et al. 1993, p. 99).
TABLE 1
Weight Definitions

<table>
<thead>
<tr>
<th>Forces applied on the body:</th>
<th>Forces applied on the support:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**DEFINITION I: "GRAVITATIONAL"**

\[ F_g = W \]

The weight of a body, \( W \), is the gravitational force, \( F_g \), exerted by the Earth. Weight and gravitational force are synonyms. \( N_{s-b} \) is an elastic contact force exerted by the support on the body. \( F_g \) (\( W \)) and \( N_{s-b} \) are NOT an "action-reaction" pair and are NOT necessarily equal. (The forces are separated horizontally only for the convenience of representation.)

**DEFINITION II: "OPERATIONAL"**

\[ N_{b-s} = W \]

Weight, \( W \), is the force exerted by the body against its support. Weight force, \( W \), is the elastic contact force, \( N_{b-s} \), exerted by the body on the support. \( N_{b-s} \), (\( W \)) and \( N_{s-b} \) ARE an "action-reaction" pair and ARE necessary equal.

The scientific correctness of the alternative definition II was discussed by King (1962), Taylor (1974), Iona (1975), and French (1995). The main criticism against the weight definition I is that the term weight is used to label two different physical entities: the gravitational force, which is a force acting-at-a-distance; and the directly measured contact elastic force, which is responsible for the result of weighing (the spring balance reading). Because of the nonunique relationship between the two, their unconditional equating, or the claim of their identity, is wrong.

Educational researchers, however, in their investigations of children’s or students’ views, usually refer to weight definition I (weight—gravitational force identity) as the only scientific concept (e.g., Andersson, 1990; Bar et al., 1994) and ignore the alternative definition II, which they regard as nonscientific. This fact substantially influenced the interpretations and inferences made in those studies. For example, the evidence that children and adults differentiate between the concepts of weight and gravitational force (Vicentini-Missoni, 1982; Ruggiero et al., 1985; Noce et al., 1988; Kruger et al., 1990) could be evaluated and interpreted completely differently, if one considers both weight definitions. The entire discussion of children’s views on weight and weight conservation as stages of the evolution of operational knowledge
would than possess a different epistemological perspective and can lead to essentially
different conclusions (Galili and Bar, in press).

As already indicated, the first goal of this study was to learn about students’ opera-
tional knowledge about weight, its content and organization. We also wanted to ver-
ify whether the investigated knowledge remains consistent when the physical context
is changed (Lawson et al., 1978), such as when a body is immersed in water, moves,
and so forth.

To facilitate the interpretation of the knowledge accumulated in this study (its sec-
ond goal), we note that weight—gravitation equivalency (definition I) is commonly
adopted in the Israeli curriculum. We endeavored to conjecture about possible origins
of students’ understanding of weight as it appears from the study. A hypothesis was
considered that some students’ ideas were induced by the specific instruction to
which they were exposed. This claim is an extension of that of Andersson (1990)
who showed that some phrases used in instruction, when understood literally, mis-
lead children’s learning of scientific terms.

From the perspective of educational psychology, this study intended to elucidate
the connection between operational knowledge and causal thinking (Piaget, 1974;
Driver et al., 1985) and provide a relevant source for attempts to explicitly under-
stand the process of learning physics (Niedderer & Schecker, 1992).

RESEARCH SAMPLE, GENERALIZABILITY

To characterize the preinstructional knowledge of our subjects, we start from the
“informal learning” element of Figure 1 as common for the whole sample. The im-
portance of this element stems from the fact that it is more frequent and durable than
any formal school instruction. It incorporates individual experience (language, books,
parental instruction, movies, TV programs, etc.) provided by modern society.
“Sensorial experience” is another common source of knowledge. It is accumulated by
individuals from an early age (sensory-motor stage of cognitive development) and is
especially relevant for the construction of a mental image of the concepts with tactile
background. Weight is definitely one of such concepts (Galili & Bar, in press). The
last shown contribution comes from “prior formal learning.” The scientific concept of
weight is originally presented in science courses of elementary and middle schools.
There, weight is introduced as the reason for the loaded spring to be stretched down
(e.g., Rockcastle et al., 1975). The instruction at this level states weight to be a result
of weighing (spring scale reading).

In the middle and high school, the student population is exposed to two levels of
instruction on weight, introductory (Educational Level-1 [EL-1] sample group) and
advanced (EL-2 sample group). The EL-1 group included 34 (ages 14–15) students
randomly chosen from four tenth-grade classes of two regular high schools. For them
weight was defined as a gravitational force, that is, the pull of gravity on an object
(e.g., Leyden et al., 1988). Commonly, the connection with the operational weight
knowledge previously provided, is left undiscussed. The advanced instruction of EL-
2 is performed as an extension of the introductory level. This instruction is adminis-
tered in the framework which is equivalent to the U.S. advanced placement physics
course, or A-level in the U.K. Thought starts from the weight—gravitational force
identity, and it is then extended by a subdivision into two auxiliary concepts of \textit{true} and \textit{apparent} weights (e.g., Sears et al., 1987).

To increase the generalizability, we included EL-2 students from two ordinary high schools, a school for more able pupils, a teachers’ college, and a university preacademic study center (all together 128), who were broken down as follows: 86 students of six grades 11–12 (ages 16–17); 15 college students (all prospective teachers of technology, adults of 22 and older); and 27 students from the university preacademic study center (adults of 22 and older).

To summarize, all subjects studied weight–gravitation within the framework of approach I. EL-1 students were instructed according to the short version (no subdivision into \textit{true} and \textit{apparent} weights), and EL-2 students were instructed according to the full version (\textit{true} and \textit{apparent} weights).

\section*{INSTRUMENTS, RELIABILITY, VALIDITY}

The methodology for exploring students’ knowledge is quite versatile (Wittrock, 1986). As this study was mainly of a diagnostic orientation (so far, there has been very little investigation of educational perspective), written questionnaires were used to collect data in a regular class environment. Despite the limited reliability of this kind of study (responses gathered in one test), it is valid in revealing the problem and direction of further in-depth investigations by more precise tools, such as multiple tests, clinical interviews, and so forth. For the same reason, we used the open format of the questionnaire, which significantly increases the diversity of the information collected. Though multiple-choice questions with sharply defined distractors could be easier to process and provide contrast information, the fixed distractors could guide students along the lines of ideas held by the researchers themselves, which students did not previously consider. That would be an undesirable effect, reducing the reliability of our inferences. The content validity of the test, and its appropriateness for the aims of this study, were established in discussions with physics education experts active at high school–university levels.

The interpretation of the results in a weighing procedure\textsuperscript{1} is highly indicative of students’ abilities to discriminate between the apparent weight and gravitational force. Therefore, the test questions were mainly, though not solely, focused on this point. To increase test reliability, wording of the test questions intentionally avoided the explicit use of “\textit{true}” and “\textit{apparent}” weights terms, inviting the subjects to recollect and assign these concepts to the situations in which they are essential. All the questions were qualitative (Table 2) and involved a variety of physical situations. Their number and diversity also contributed to the reliability of the results. Overlapping (in some cases) contents contributed to the validity of collected information and compensated for the lack of direct contact with the subjects. To facilitate interpretation of responses and our further discussion, we provided clarifying comments regarding expected answers to the employed questions in both weight frameworks (Table 2).

\textsuperscript{1}Here, by “weighing” we always mean the measurement performed with a spring balance. By “weighing results,” we mean the results of this procedure.
### TABLE 2
The Test Questionnaire (Translated from Hebrew)—Each Question Was Accompanied with an Illustrative Drawing

<table>
<thead>
<tr>
<th>Questions</th>
<th>Weight Framework I</th>
<th>Weight Framework II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. An astronaut, in a spaceship orbiting the Earth wants to check the weight labeled “1 kg.” He is using a very accurate spring scale. What are the scale readings and the inferences the astronaut makes regarding the 1-kg-weight's weight when the satellite is coasting at a height of: (a) 100 km above the Earth's surface? (b) 200 km above the Earth's surface?</td>
<td>The spring balance shows the <strong>apparent weight</strong> which is an exact zero. The <strong>true weight</strong> is slightly less than on the ground (-3%; -6%).</td>
<td>The spring balance shows a weight which is an exact zero. The <strong>gravitational force</strong> is slightly less than on the ground (-3%; -6%).</td>
</tr>
<tr>
<td>2. Another astronaut is located in a very high tower. He wants to solve the same problem as the astronaut in the coasting satellite. The tower is so high that he is at the same height as his colleague in the satellite. The same accurate spring scale is used. What will be his weighing results and his inferences regarding the 1-kg-weight's weight when: (a) the tower height is 100 km? (b) the tower height is 200 km?</td>
<td>The spring balance shows a slightly reduced (comparative to on ground) <strong>apparent weight</strong> (-3%; -6%). The <strong>true weight</strong> is equal to the <strong>apparent weight</strong>.</td>
<td>The spring balance shows a weight which is slightly less than on the ground (-3%; -6%). The <strong>gravitational force</strong> is equal to the <strong>weight</strong>.</td>
</tr>
<tr>
<td>3. The same problem of checking weight is now being solved by a person who floats in the sky in the basket of a hot-air balloon. (a) What are his results of weighing? Will it be more, less or the same as by the weighing on the ground? (b) What is his inference about the weight?</td>
<td>The spring balance shows an <strong>apparent weight</strong> which is the same as on the ground.</td>
<td>The spring balance shows a weight which is the same as on the ground.</td>
</tr>
<tr>
<td>4. Do you think that the weight of a box located in a submarine, submerged deep under the water surface, would be different from that on the Earth's surface? A very precise spring scale is available.</td>
<td>The <strong>true weight</strong> is numerically equal to the <strong>apparent weight</strong>.</td>
<td><strong>Weight</strong> is numerically equal to the <strong>gravitational force</strong>.</td>
</tr>
</tbody>
</table>

continued
5. Imagine yourself in a capsule located just next to the Earth’s center. You want to determine the weight of a box, and a spring scale is available. Will your inference be different from that made on the Earth’s surface?

6. A weight labeled “1 kg” is suspended from a spring scale and enclosed in a bell jar. The air is then pumped out of the jar.
   (a) Does the weight of the 1-kg weight change? How?
   (b) Does the scale reading change? How?

7. A weight labeled “1 kg” hangs by a cord from a spring balance and is submerged in water contained in an open beaker.
   (a) Does the weight of the 1-kg weight change? If it does, why and how?
   (b) Does the scale reading change? If it does, which way?

8. Imagine yourself a skydiver, and that you want to know the weight of a small box you have. You have a spring balance with you. If you perform a weighing during your jump, will your inferences about the weight of the box be different from those you would make at rest on the Earth’s surface? Consider two situations:
   (a) You are in a free fall (just at its beginning, when your parachute is still close).
   (b) You in your slow (constant speed) descent (with an open parachute).

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**TABLE 2—Continued**

The Test Questionnaire (Translated from Hebrew)—Each Question Was Accompanied with an Illustrative Drawing

<table>
<thead>
<tr>
<th>Questions</th>
<th>Weight Framework I</th>
<th>Weight Framework II</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Imagine yourself in a capsule located just next to the Earth’s center. You want to determine the weight of a box, and a spring scale is available. Will your inference be different from that made on the Earth’s surface?</td>
<td>The spring balance shows zero apparent weight which is also the true weight.</td>
<td>The spring balance shows zero weight which is equal to the gravitational force.</td>
</tr>
<tr>
<td>6. A weight labeled “1 kg” is suspended from a spring scale and enclosed in a bell jar. The air is then pumped out of the jar.</td>
<td>The apparent weight slightly increased. The true weight remain the same.</td>
<td>Weight and gravitational force remain the same.</td>
</tr>
<tr>
<td>7. A weight labeled “1 kg” hangs by a cord from a spring balance and is submerged in water contained in an open beaker.</td>
<td>The apparent weight decreases. The true weight remains the same.</td>
<td>Weight and gravitational force remain the same.</td>
</tr>
<tr>
<td>8. Imagine yourself a skydiver, and that you want to know the weight of a small box you have. You have a spring balance with you. If you perform a weighing during your jump, will your inferences about the weight of the box be different from those you would make at rest on the Earth’s surface? Consider two situations:</td>
<td>(a) The apparent weight is zero. The true weight as on the ground. (b) The apparent weight is as on the ground. The true weight coincides with the apparent weight.</td>
<td>(a) The weight is zero. The gravitational force is as on the ground. (b) The weight is as on the ground. The gravitational force is as on the ground.</td>
</tr>
</tbody>
</table>
9. A passenger in a moving elevator is interested in knowing the weight of a box. Only a spring scale is available. Compared with being on ground, will his inference about the weight of the box be influenced by:
(a) the accelerated movement of the elevator upwards?
(b) the constant speed movement of the elevator downwards?

(a) The apparent weight increased. The true weight remained the same.
(b) The apparent weight remained same. The true weight coincides with the apparent weight.

10. A person measures the weight of a box using an extremely sensitive spring scale. He wonders whether or not the Moon, just passing over him, influences his measurement and changes the weight. Did the weight change under the influence of the Moon?

The spring scale shows the apparent weight which is as if there was no Moon. The true weight is reduced due to the Moon's attraction.

11. An object placed on the ground is attracted by the Earth with the force of 100 N.
(a) What is the weight of the object?
(b) According to Newton's third law, the Earth attracts the body with exactly the same force. Could you claim that the weight of the Earth is 100 N too? Explain.

12. (a) What is the weight of the Earth?
(b) Is the weight of the Moon more, equal, or less than of the Earth?

Earth's rotation is neglected.
Gravitational force change with distance to Earth is neglected.
Air resistance is neglected.
The questions can be nonexclusively grouped according to different factors of potential influence on students’ weight—gravitational considerations.

**Group 1** (location of weighing): Q1, Q2—100–200 km above the Earth; Q3—in the sky, not far from ground; Q4—inside a submerged submarine; Q5—near the Earth’s center.

**Group 2** (the medium or environment in which the weighing takes place): Q1, Q2—outside the Earth’s atmosphere; Q3—inside the Earth’s atmosphere; Q4—in a submarine; Q6—in vacuum (at sea level); Q7—in water (at sea level).

**Group 3** (the motion of the weighing device): Q1—in an orbiting satellite; Q2—at rest in a very high tower; Q3—floating in the sky; Q8a—during an open-air “free” fall; Q8b—during an open-air fall suppressed by air friction to the terminal speed; Q9a—in a close ascending accelerated cabin; Q9b—in a closed cabin descending at a constant speed; Q10—in free gravitational movement relative to a planet other than the Earth.

As a matter of fact, different parameters interweave in any real physical scenario, and one can only approximately consider a case of a single influential factor. Inclusion of a comparatively high number of questions enables us, from comparison of responses to partially redundant questions, to look at their similarities and differences and to assess students’ apprehension.

**Group 4** questions probed students’ knowledge about weight in an “astrophysical” context in which gravitational weight definition I is especially ambiguous. Such a situation can reveal other shortcomings of understanding of weight in relation to mass, gravitational force, action–reaction forces, tides phenomenon, and so forth. Q10 included more than one gravitational attractor and the “true weight” which cannot be measured by weighing. Q11 was related to the fact that the weight term is associated only with one of the “action–reaction” pairs of gravitational interactions. Q12 asked about the weights of the Earth and the Moon, which are physically undefinable though plausible to the lay ear. The ambiguity of the suggestion to sum over all gravitational forces gravitational weight definition I (quoted below) was expected to be a barrier for students’ understanding, which can puzzle and mislead.

All questions used in this study were aimed mainly to reveal the sides of conceptual knowledge which often remain hidden in a common problem-solving setting.

**FINDINGS AND THEIR INITIAL INTERPRETATION**

**Q1 and Q2**

In both tasks, weighing took place at the same distances from the Earth’s surface. However, the essentially different results of weighing had to be predicted. The weighing on a tower would yield the scale reading only slightly lower from those obtained on the ground (3% on 100-km elevation). In contrast, an exact zero scale reading is observed by an astronaut in a satellite due to its nonstopping free fall. Weight definition I would imply the same “true weights” in Q1 and Q2, but contrasting “apparent weights” (Table 2). However, over 90% of the students (except a few from EL-2) responded with only one answer and did not discriminate between weight and the scale reading. The categories of responses (Table 3) reflect the ways of reasoning.
<table>
<thead>
<tr>
<th>Categories</th>
<th>Unchanged Weight</th>
<th>Additional Force Influence</th>
<th>Distance (Height) Dependence</th>
<th>Environment (Medium) Influence</th>
<th>Motion Influence</th>
<th>Not Explained Increase</th>
<th>Not Explained Decrease</th>
<th>No Answer/Do Not Know</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EL-1</td>
<td>EL-2</td>
<td>EL-1</td>
<td>EL-2</td>
<td>EL-1</td>
<td>EL-2</td>
<td>EL-1</td>
<td>EL-2</td>
</tr>
<tr>
<td>Q1 Satellite</td>
<td>3a</td>
<td>6</td>
<td>0</td>
<td>11</td>
<td>56</td>
<td>45</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q2 Tower</td>
<td>21</td>
<td>12</td>
<td>0</td>
<td>1</td>
<td>50</td>
<td>59</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q3 Balloon</td>
<td>34</td>
<td>16</td>
<td>6</td>
<td>3</td>
<td>46</td>
<td>62</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q4 Submarine</td>
<td>53</td>
<td>20</td>
<td>15</td>
<td>14</td>
<td>12</td>
<td>18</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q5 Earth's center</td>
<td>21</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>41</td>
<td>53</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q6 Vacuum</td>
<td>38</td>
<td>36</td>
<td>35</td>
<td>46</td>
<td>0</td>
<td>6</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Q7 Water</td>
<td>3</td>
<td>20</td>
<td>53</td>
<td>71</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Q8a Open-air free falling</td>
<td>29</td>
<td>27</td>
<td>24</td>
<td>4</td>
<td>15</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q8b Open air constant speed falling</td>
<td>35</td>
<td>25</td>
<td>24</td>
<td>22</td>
<td>12</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q9a Rising accelerated cabin</td>
<td>21</td>
<td>4</td>
<td>41</td>
<td>65</td>
<td>24</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q9b Constant speed descending elevator</td>
<td>41</td>
<td>63</td>
<td>9</td>
<td>5</td>
<td>27</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q10 Moon's influence</td>
<td>12</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>79</td>
<td>84</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Figures represent percentages.*
The claim about weight dependence on the distance was predominant: response distributions are similarly well centralized in the “distance (height) dependence” category. A salient feature of this response is the unconditioned equation between the gravitational force and weight, further extended to the scale reading.

The weight decreases as they move away from the Earth . . . (1-1)

The weight is zero at both distances according to \[ G \frac{Mm}{r^2} \] . . . (1-2)

Predictions of “not explained decrease” of weight were also common in both sample groups and could reflect the same apprehension of weight. The main difference between the responses to Q1 versus Q2 was that one quarter of the students stated exact zero weight gravitation in the satellite, EL-1 21%, EL-2 25%, instead of EL-1 5.9%, EL-2 6.8%, who predicted zero weight on a tower. Zero weight predictions were not grouped in a separate category in Table 3, as they were reasoned differently. A claim of zero weight itself, which is supported solely by the distance argument, or left unexplained, clearly does not fit with definition I. In general, all answers to Q1 that do not discriminate between apparent weight and true weight are wrong (Table 2). In contrast, a similar lack of discrimination in Q2 does not lead to a formally wrong answer.

The larger proportion of “unchanged weight” answers and the fewer “unexplained decrease” responses to Q2, compared with Q1, might show recognition of parameters other than distance (which was neutralized by equality).

Another way to justify an intuitive tendency to reduce weight (especially in the satellite environment) manifested itself in an “additional force” reasoning:

The centrifugal force cancels the weight in the orbit. (1-3)

Or, explicitly elaborated:

In the satellite orbiting on the constant trajectory there is weightlessness. There is a force of attraction towards the center of the Earth and there is a contrary force, centrifugal, which pushes it outside. These forces neutralize each other and keep the body moving on a circular trajectory. There is no gravitational force inside the satellite revolving around the Earth because there is no weight there, and if there is no weight, there is no gravitation. (1-4)

Q3, Q4, and Q5

Tasks Q3 and Q4 were designed as complementary in location: slightly above and below the sea level. A numerically insignificant distance change of the gravitational force allowed identical answers (Table 2). By contrast, the actual responses to both questions were often neither similar nor correct, and varied between levels (Tables 3). The formally correct answer (“unchanged weight”) did not prevail and, when given, did not always indicate the correct understanding:

Weight has not changed as it is still in the atmosphere. (3-1)

Weight has not changed as it is still in the region of the Earth’s attraction. (3-2)
“Distance [height] dependence” of weight was frequently mentioned, commonly supporting the prediction of the decreased weight, except for a few students who wrote:

. . . The weight is greater there. If you increase the height the force of attraction to the center of the Earth becomes bigger, like the force on the spring, it increases. (3-3)

In the context of a submarine the prediction of distance dependence of weight commonly appeared as a claim:

. . . it is closer to the Earth’s center, the weight will increase . . . (4-1)

Very few answers included the correct, though quantitatively insignificant, distance dependence of the gravitational force:

. . . the water above the submarine does not contribute to the gravitational pull on the Earth [inside the submarine]. (4-2)

“Additional force influence” (Archimedes’ buoyant force) was mentioned by a few in regard to the weight alterations during floating in the balloon.

The weight will be decreased due to the buoyant force. (4-3)

In the submarine setting, “additional force influence” reasoning manifested itself in the claim:

The weight increased because of the additional pressure of water. (4-4)

Some claims of “unchanged weight” were reasoned on the basis of the capsule’s protection against pressure:

. . . the water cannot influence the weight as the weighing is inside the submarine and its body resists the water pressure . . . (4-5)

Such a response can testify to the same rationale: weight (whatever it means) could be influenced by an additional nongravitational parameter (water pressure). The high rate of “not explained increase” of weight answers in the submarine question might indicate the same considerations.

Contrary to expectations, only a few answers to Q5 mentioned zero weight (Table 2). Those represented a small fraction of the “distance dependence” category. Even those were often obscure:

There is no attraction force there [at the Earth’s center] . . . (5-1)

There is nothing to attract it [the body] there [at the Earth’s center] . . . (5-2)

In the framework of the simplest model, the Earth’s density is uniform, and mechanics predicts the decreases of the gravitational pull when moving into the Earth, toward its center. The reason for this was first shown by Newton: a spherical shell of matter does not gravitationally influence the bodies located inside it. Hence, EL-2 students could argue for the weight decrease. In reality, however, the Earth’s density is not uniform (Halliday et al. 1993, p. 416) and the gravitational force increases for the submarine. This uncertainty did not represent a difficulty (as it could for grading results in terms of “correct—incorrect”) as we looked exclusively for the considerations applied.
The rest of the answers were diverse (Table 3). Some of the arguments already registered in Q3 and Q4 showed significantly stronger answers than those of Q5. Two thirds of EL-2 and one third of EL-1 predicted weight increase. Commonly, this claim was justified by approaching the center of Earth:

It is there, very close to the point from which the force originates, so the force of attraction must be very large . . . (5-3)

Some students argued with the formula \( F_{\text{grav}} = G \frac{m_1 m_2}{r^2} \). Its incorrect application, when one substitutes small distances in the denominator, misled many students, who wrote:

. . . according to Newton's law, the closer you are to the Earth's center, the bigger the force pulling things is . . . (5-4)

In other responses, the “enormous pressure” inside the Earth was mentioned as a factor causing weight increase (“additional force influence” category):

The weight will be much bigger. There is so much ground above it . . . (5-5)

Some of those (more in EL-1) who claimed here “unchanged weight,” argued by use of the standard formula, \( W = m \cdot g \), which does not include, as they explained, anything else but constants.

Q6 and Q7

Q6 and Q7 essentially presumed the ability to imply about weight from weighing performed in a medium, air, or water. Only a few EL-2 students explicitly operated with apparent and/or true weights, mostly in Q7 (water medium), where students mentioned that the “real” (true?) weight did not change. Students often manipulated solely with the target concept—“weight,” which made their responses ambiguous and hard to interpret. About a third of them predicted “unchanged weight” in vacuum, less—in water (Table 3) which would fit the “true weight” concept. Students commented:

None of the parameters, \( g, m_1, m_2, r \), has changed . . . (EL-2) (6-1) (7-1)

Weight has no connection with air . . . (EL-2) (6-2)

The air pulls the weighed body in all directions . . . (6-3)

The air (water) pressure is the same in all directions . . . (6-4) (7-2)

To support predictions of weight changes, which would fit the “apparent weight,” students noted “additional force influence”:

The weight increases in a vacuum as the air stops pushing from underneath . . . (6-5)

The weight increases in a vacuum as the air static friction is no longer present and the attraction rises. . . . Friction with air reduces the attraction. (6-6)

Weight is reduced in water, water pushes the body back . . . (7-1)

Water resists the body more than air and hence it reduces its weight. This explains why it is easier to lift a body in water than outside, with the resistance of air . . . (7-2)
Weight will be reduced, as a part of the force originally active is now dispersed (changed its form) into other forms of energy . . . (7-3)

Water resists and, hence, it reduces the gravitation . . . (7-4)

Due to the force of Archimedes, the weight will be smaller . . . (7-5)

Students explicitly addressed the medium, or vacuum, as causing reduction in weight, gravitation, and even in mass (“environment [medium] influence”):

Weight has changed in water as $g$ has changed there . . . (7-6)

In a void there is no attraction force. Weight no more has any sense as there is nothing that pushes it downwards because in the absence of air the gravitational forces do not work any more . . . In a void all bodies move without any influence of weight. (6-7)

In an absolute vacuum the force of attraction cannot act (EL-1) (6-8)

Void neutralizes forces acting on the weighed body from the other bodies and stars around . . . (6-9)

Weight has been reduced. It is similar to the weight when it is on the Moon; there is no air there, including oxygen, and therefore, due to low gravitation, the weight (and mass) decreases. (EL-2) (6-10)

Q8, Q9, and Q10

In these tasks, weight was considered during vertical movement. The situations chosen were similar in regard to the “true weight,” but significantly different with respect to the “apparent weight” (weighing results). In their responses, students continued to use the “weight” term in various senses, often not specifying or explaining (“unexplained increase” and “unexplained decrease”).

EL-1 students, significantly, continued to employ “distance dependence” of weight in all Q8 and Q9 tasks. Other significant categories were “additional force influence,” especially regarding a rising elevator, and “unchanged weight,” especially in the constant speed elevator. Those responses of “unchanged weight,” when justified by no change in “m” and “g,” as well as predictions of “distance (height) dependence” of weight, would fit with “true weight.” The answers often exposed the belief that the weight changes due to the distance change are directly registered by weighing, whatever other conditions (such as a free fall or acceleration) may be. The commonality of this belief has already been recognized. Students wrote:

Weight was originally decreased by elevation, then it goes and increases when the distance to the Earth decreases in falling . . . (8a-1)

At first, the elevator went up, now it goes down to its starting point, so its weight is getting bigger . . . (9b-1)

The acceleration of the attraction towards the Earth is now [at that height] less than 9.8 and the mass is still constant, that is why the m·g is now less than it was . . . (8a-2)

About 20% of students predicted zero weight in falling (not isolated in a separate category as was variously reasoned). It would fit “apparent weight” and was shown more at EL-2 regarding free falling:
It is a situation of weightlessness, so that there is no weight then . . . ["unexplained decrease"] (8a-3)

It is a free fall with the relative acceleration equal to zero, hence, \( m \cdot g \) will be zero too . . . ["motion influence"] (8a-4)

Some answers stated "additional force influence," when forces, besides gravitational, contributed to weight, causing its reduction or rise:

Weight is smaller when the parachute is opened due to the air resistance. (8b-5)

The "motion influence" on weight was shown:

The relative acceleration is now smaller [with a parachute] but more than zero, due to the air resistance, so the weight is decreased . . . (8b-6)

The same category includes reasoning with notions of escaping support, feelings of flying, which could both fit formal knowledge (free fall), or contradict it (Q9b):

The elevator provides the feeling of flying (floating), depending on the speed, and so, as in flying, the weight decreased . . . (9b-2)

The acceleration acting on the body increases its weight . . . (9a-3)

There is a contradiction between the movement and the gravity, so the weight will decrease . . . (9a-4)

A significant advantage of the students that had received advanced instruction (EL-2) was well observed in Q9b (constant velocity) where the EL-2 majority (above 60%) predicted unchanged weight, fitting both weight definitions. EL-2 curricular studies include Galileo’s relativity principle.

In Q10, the measurer, spring balance, and weighed body, together with the Earth, are all in a common free gravitational motion relative to the Moon, additional gravitational attractor. Being equivalent to free falling, this implies no influence on weighing. Despite commonly incorrect responses valuable data were collected as our intention was not to grade but to explore students’ knowledge. Most of our students (about 80%) argued for weight changes due to the additional gravitational force possibly registered in weighing, though highly diminished (by distance). They suggested accounting for the weighing result by vectorial summing of both gravitational attractions. The resulting net force on the body was identified with its weight and scale reading. This trend of thought contradicts both weight definitions. The resultant gravitational force had to be considered “true weight,” in contrast to the “apparent weight,” which had to be implied as unchanged. The zero influence of Moon on the scale reading is due to the “free fall” relative to it.

Another argument deserves mention as manifesting the same coherent knowledge about weight:

Certainly, the weight will be changed, the Moon will influence the weight of the body, just as tides in the oceans are caused by the Moon’s attraction . . . (10-1)

\[\text{This students’ confusion deserves a brief comment. As only a change in gravitational force is what counts for tides, this phenomenon is not relevant for a small body (or in a uniform gravitational field). To avoid confusion some authors define a “new” kind of force—“a tidal force” (Tipler, 1990, p. 317), or “a tide generating force” (Benson 1991, p. 273), which is a residual gravitational force, responsible for the tides, but having nothing to do with the results of weighing.}\]
Only few EL-2 students identified the situation as equivalent to a “free fall” and implied no changes in the apparent weight.

Some responses of “unchanged weight” pointed out the aptitude of the weight concept only for an on-Earth location:

Weight is only defined relative to the Earth’s attraction . . . (10-2)
Weight exists only near the Earth . . . (10-3)
The gravitational attraction of the Moon can’t reach the Earth . . . (10-4)

Q11 and Q12

A clearly puzzling statement in Q11 regarding Earth’s weight spurred students to contrive an objection. About a third, though rejecting the absurd claim, did not reason. The rest found the following ways to object (Table 4):

- **“Weight is not gravity” or “weight is not defined”:**
  ... weight is not necessarily equal to the attraction force . . . (11-1)
  ... the attraction force is equal to 100N, but the weight of the Earth is much bigger . . . (11-2)
  ... the Earth pulls the weight not with the maximum force . . . (11-3)
  ... it could be 200N in the same way . . . (11-4)
  ... the Earth does not weigh . . . (11-5)

- **“Weight is mass”:**
  ... weight is not a force . . . (11-6)
  ... the weight of the Earth is huge, but I do not remember the numbers . . . (11-7)

**TABLE 4**

Distributions of Students’ Responses to Q11 and Q12

<table>
<thead>
<tr>
<th>Categories</th>
<th>EL-1</th>
<th>EL-2</th>
<th>EL-1</th>
<th>EL-2</th>
<th>EL-1</th>
<th>EL-2</th>
<th>EL-1</th>
<th>EL-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight is Not Gravity (or Not Defined)</td>
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<tr>
<td>Weight is Mass</td>
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<tr>
<td>Weight is Only Relative</td>
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<td>Attractions Are NOT Equal</td>
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<tr>
<td>No Answer/Do Not Know</td>
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</tr>
<tr>
<td>Q11 — Weight “reciprocity”</td>
<td>6.1 *</td>
<td>35.2</td>
<td>6.1</td>
<td>9.4</td>
<td>24.2</td>
<td>15.6</td>
<td>24.2</td>
<td>9.4</td>
</tr>
<tr>
<td>Q12 — Weights of planets</td>
<td>24.2</td>
<td>21.3</td>
<td>9.1</td>
<td>22.1</td>
<td>54.6</td>
<td>35.4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*Figures represent percentages.
all things have their specific weights, and the weight of the Earth is not 100N . . . (11-8)

**"Weight is only relative":**

. . . There are many other bodies which also attract the Earth, therefore, its weight is different . . . (11-9)
Contrary to mass, the weight of the body is relative . . . (11-10)

**"Attractions are not equal":**

I don’t really think they pull each other equally (EL-1) (11-11)
The small weight has no force to attract the Earth . . . (EL-1) (11-12)
. . . . \( F = m \cdot g \) . . . but the mass of the Earth is huge and the weight of the body is very small, so the influence of the body could be neglected . . . (11-13)
. . . but in this case the mass of the Earth is much bigger, so it attracts the body and not the opposite . . . (11-14)
. . . it is the Earth which acts on the body and not the opposite . . . (EL-1) (11-15)
The attraction of the weight is spread over the huge mass of the Earth, then it will not result in the force of 100N . . . (11-16)
Both of them attract each other but the Earth has more force of attraction than the other body . . . (11-17)
Students’ responses to questions about the weights of the Earth and the Moon had a similar spectrum of reasoning with a more pronounced occurrence of the “weight is only relative” category:

To know the weight of the Earth, I have to summarize the forces from all the stars and planets . . . (12-1)

**THE SECOND INTERPRETATION OF RESULTS AND DISCUSSION**

As an epistemologically important remark, we mention that a supporting surface (Table 1) could be viewed generally as a plate of a scale with an elastic spring underneath. If so, what is measured in the procedure of weighing is solely the force exerted on the support—the elastic force, \( N_{b-s} \) (“b-s” stands for “body→support”). This force causes spring deformation, as well as a muscular effort perceived by our senses when we prevent the natural falling of things. We register only this contact force and not the gravitational force. According to newtonian mechanics, the gravitational force happens to be numerically equal to the elastic force, but not in all cases. Thus, this equality holds in the state of rest, but is violated by any accelerated motion (e.g., Earth’s rotation). Within the epistemological perspective, the contact force plays a unique role in the consolidation of the mental image of weight.

\(^6\)The state of rest here presumes a static, nonrotating Earth.
WEIGHT CONCEPT

Gravitational weight definition I, at least its introductory version (EL-1), ensures the gravitating masses, and the distance(s) between them, to be the only parameters to cause weight. And, when masses are kept unchanged, distance becomes the only remaining variable. However, our data show that students construct knowledge in a more flexible manner. Knowledge varies conforming to a wide range of reality but often contradicts formal weight definition. This fact reflects significant difficulties in assimilation of the dictum which identifies weight with gravitational force.

Is it surprising? The science curricula of elementary schools incorporate the identification weight = weighing results (e.g., Rockcastle et al., 1968). This linkage, weight—weighing results, is further reinforced in junior high school (e.g., Leyden et al., 1988). Further in the course of physics instruction, another identity, weight = gravitational force, is introduced. Students are provided with two identities with a common concept—weight. It is seemingly natural then, to unite them into one. Thus, the literal understanding of the gravitational weight definition often follows the poor assimilation of the advanced instruction to distinguish between weight, gravitational force, and weighing results.

Moreover, a calibrated spring scale presents a unique force-meter of practical use in all science—physics classes (Arons, 1990). Both weight and gravitational force, as any other force, are expected by students to be measured by the force-meter.

Finally, the strongest etymological similarity between the two terms, “weight” and “weighing,” petrifies their identify. As previously noted, the prerogative to discriminate between weight and weighing results is preserved for the advanced placement course (e.g., Halliday et al., 1993) and, as such, is available for a small minority of students. Our data show that the reality is even more complicated: in many cases, the advanced instruction does not solve the confusion. Contrary to instruction, EL-2 students often practice an alternative knowledge in which weight—gravitational identity is interwoven with other beliefs. As a result, the knowledge shown by EL-2 students is often not superior to that of EL-1 students, indicating an essential problem.

A pronounced trait of our data is that EL-2 students very often ignore the terms “apparent” and “true” weights leaving them practically out of explicit use. This “simplification” obviously causes confusion in knowledge and ambiguity in its presentation. Though one could, in some cases, interpret students’ responses as a tacit application of these concepts, this situation is, of course, not satisfactory and presents a problem beyond mere communication.

We found it possible to represent students’ operations with weight as the application of few operational schemes. These schemes might not really represent students’ cognitive system, but we can use them as if they were, to obtain a comprehensive and short description of students’ thinking. In a number of aspects these schemes do not conform to the formal knowledge and present an alternative coherent structure. As such, they can coexist and complement each other.

**Scheme 0.** There is only one weight concept.

**Scheme 1.** Weight (or weight force) is directly and unconditionally related to the empirical weighing results obtained by means of a calibrated spring scale.
Scheme 2. Observable or predictable alterations of weight are related to distance parameter, according to the rule: “more distance less weight.” This relation is seemingly the first coming to mind.

Scheme 3. Observable or predictable alterations of weight are related to other forces or pressure (of air, water, or ground), which can compete with the gravitational force causing weight reduction or addition.

Scheme 4. Weight is due to the surrounding medium. This scheme extends scheme 3, claiming the existence, creation, or transfer of the weight force by the medium (air).

Scheme 5. Observable or predictable changes of weight are related to the movement of the object (observer). Within this framework, sensations associated with movement (such as losing support in falling or floating) are interpreted as changes of weight—reduction or addition.

Scheme 6. Weight is identified with an inherent and invariant quality of the body. This use is reminiscent of mass, though students often attribute to the body both constant characteristics—mass and weight.

In many ways, these schemes, which represent students’ postinstructional knowledge, contradict the ideas insured by the instruction and the intentions of physics teachers regarding the knowledge “inducted” in students’ minds. The following review of the data illustrates this claim.

In Q1 and Q2, the majority of the subjects ignored the taxonomy of weight suggested by the instruction. They worked with only one weight concept (scheme 0), which was not distinguished from the scale reading (scheme 1). Furthermore, those students, who claimed identical scale reading in Q1 and Q2, justified it by equal distances to the Earth (scheme 2). The explanations (1-1, 1-2) were regarded as plausible and exhaustive, despite the strong contrast between the physical contexts, as seen by an expert.

The indiscrimination between the two physical settings, Q1 versus Q2, exactly fits the scheme 1. An analogy between the two (equal distances) could encourage the equation between a familiar, though badly understood, satellite situation and the imaginary, high tower. The idea of “the same weights at the same distances” inducted an often observed inference of the extremely exaggerated distance attenuation of the gravitational force. An alternative understanding of “weightlessness,” manifested in a “floating reality” in a satellite, was constructed. Thus, weightlessness is explained by the drastic reduction of gravitational force with distance (schemes 0 plus 1, plus 2). This scheme predicts a greatly diminished but still a finite and, in principle, detectable weight. This understanding is in striking contradiction with the newtonian doctrine about free fall, no matter what weight definition is adopted. This view on “weightlessness” makes useless the apparent and true weight concepts, preventing their assimilation.

Another operational scheme was identified in the same context. To explain zero weight in a satellite (probably inspired by the apparent floating of objects) some students recruited an additional force (a centrifugal force) to cancel weight (1-3, 1-4). This strategy must well reflect prenewtonian common sense, as already in the sixteenth century it was used by Borelli to nullify the weight of nonfalling planets (Butterfield, 1965). In teaching perspective it was discussed by Gardner (1981,
WEIGHT CONCEPT

1984) and Galili (1993). In terms of weight-operational schemes it indicates a combination of schemes 1 and 3. This approach is inconsistent with weight definition I: once weight is a gravitational force, no nongravitational force can, by definition, contribute to it. This strategy is equivalent to the modification of the weight concept in the spirit of its operational definition. Yet, it does not coincide with the weight definition II, because the latter defines weight exerting on the support and not on the body.

The data of Q3 (floating balloon) confirmed scheme 2 (weight-distance relation) at a similar rate to Q1 and Q2. The insensitivity to the extreme smallness of the actual effect, when implying the observed weight change, might indicate a distorted scale of weight-distance dependence, similar to that shown in the satellite context.

Another interpretation of students' predictions of weight changes in the balloon settings is the state of floating itself. Though different from that of astronauts in a satellite, floating of a balloon might be perceived by students as evidence of changes in weight when the sensations associated with floating are identified as directly perceived weight alterations (scheme 1).

Scheme 2 was employed in the submarine environment, though the claim "the less distance (to the Earth's center)—the more weight" (4-1), was already scientifically incorrect. The "classroom" knowledge would imply the decrease (albeit very small) of the gravitational force when the object is located under the Earth's surface. This was recognized by a few students (4-2).

Those who employed scheme 3, viewed the pressure from the medium (4-4, 4-5), or the buoyant force (4-3), as directly contributing to weight and causing its increase (pressure) or decrease (buoyant force).

One could mention the peculiar character of students' apprehension of the buoyant force as causing reduction of weight inside the submarine. This understanding can be interpreted as a manifestation of a "global approach" to the physical setting—a specific trait of children's thinking. Piaget (1972) elaborated on this "synthetic" nature of the child's perception. In the physics problem-solving context, it was observed as a failure to single out one item from a complex system (e.g., Galili & Bar, 1992). In Q4, students "integrated" the spring scale and the suspended weight with the submarine. But whatever interpretation, the account with the buoyant force in this context means admission of water action at distance, similar to gravitation.

Q5 weighing next to the Earth's center sharpened the exposure of the already shown schemes. Thus, the additional pressure argument (4-4), scheme 3, reappeared (5-5). It was the same intent to incorporate a scalar factor (pressure) as contributing to weight, shown before and interpreted as an operational approach to weight. Here it contradicts both weight definitions (Table 2).

Furthermore, an inappropriate understanding of the weight-distance dependence within scheme 2 (4-1) reached its extreme in Q5 when a strong increase in weight was predicted (5-3, 5-4). One might relate it to a literally interpreted portrayal of gravitational attraction. In textbooks, the gravitational force is often shown as directly exerted on the center of a solid Earth (Fig. 2a; e.g., Halliday et al. [1993, Fig. 15-3, p. 413]). One might suggest, as pedagogically preferable, introduction of the same fact by a more elucidating, though less common, representation (Fig. 2b; e.g.,
Abel et al. [1991, p. 62]). We frequently observed this “literal” interpretation and the suggestion that a force originated from the Earth’s center. Obviously neglected here, the instruction commonly suggests to sum over multiple interactions between small constituents of the gravitating bodies to obtain the net gravitational force. Identifying the Earth’s center with a mysterious origin of force, students inappropriately apply a small number \( r \) to Newton’s formula,

\[
F_{\text{grav}} = G \frac{m_1m_2}{r^2},
\]

disappointingly providing a totally incorrect result.

Scheme 3 clearly emerges in many responses to Q6, and Q7. Predictions of weight changes (6-5 to 6-10, and 7-1 to 7-6), as well as of an unaltered weight when justified by the canceling of the medium, influence all directions (6-3, 6-4). Students saw air (water) pressure as a mechanism of medium influences on weight. This apprehension seemingly indicates an established mental image of weight as the measure of heaviness (schemes 0 and 1).

Moreover, the explicitly claimed nullification of the gravitational force in or by the vacuum (6-7 to 6-10), could have another strong psychological underpinning (scheme 4). The stipulation of weight by air presence/pressure has been reported by Minstre1l (1982), Ruggiero et al. (1985), and Noce et al. (1988). Quotes (6-7, 6-9, 6-10) point to the origin of this belief: a naive inference from common observations. Namely, watching the odd reality of weightlessness (orbiting satellite) and a reduced weight (Moon) may encourage this reasoning. A child causally links gravitation with the absence of air in the interstellar space. One might represent the cognitive genesis of this erroneous scheme by a logic chain of scientifically unfounded association:

\[
\begin{align*}
\text{IF} & \quad \text{weightlessness (reduced weight)} \quad \text{is a reality in a satellite (on the Moon)}; \\
\text{AND} & \quad \text{there is no air around a satellite (on the Moon)}; \\
\text{THEN} & \quad \text{the absence of air causes weightlessness (reduced weight)}. \\
\end{align*}
\]

There might seem to be a controversy: in Q1 and Q2, context schemes 3 and 4 were not registered despite the vacuum environment. Scheme 2 prevailed there and the directly observed weightlessness (reduced weight) in space context was explained by the distance parameter. This effect could be due to the written format of our test in
which one answer was sufficient and, therefore, the strongest scheme suppressed all the others. In on-ground vacuum (Q6), however, scheme 2 was neutralized, allowing other schemes to show up. Though “weight is gravitational force” remained as the central conception, competitive reasoning appeared, alternatively explaining the “floating reality” by another salient common feature of both settings—vacuum.

But whether scheme 2 (distance—weightlessness) or scheme 4 (vacuum—weightlessness), or scheme 3 (medium influence) is adopted, students address the experience (real or imaginary) of weighing. Its interpretation is seemingly related to the tactile image of weight, constructed by a child, and later modified, under the influence of a new experience (observations). This is a complex process of welding—fusion of ideas resulting in consolidation of scheme 1 within scheme 0 (Galili and Bar, in press). Thus, in Q1 the schemes 1 and 2 were primary and schemes 3 or 4 secondary. In Q6 schemes 3 and 4 were first.

We see in past the same intuitively created scheme guiding great minds’ apprehension of weight: “Weight is a measure of the heaviness and lightness of one thing compared to another by means of a balance.” (Euclid, 1961, p. 24)

A setting of immersed body (Q7) always provoked further elaboration of knowledge about weight. Newton commented in *Principia*:

> But those things [immersed in water] which neither by preponderating descend, nor, by yielding to the preponderating fluid, ascend, although by their true weight they do increase the weight of the whole, yet comparatively, and as commonly understood, they do not gravitate in water. (Newton, 1978, p. 198)

What did Newton mean by “they do not gravitate in water”? Did he criticize a popular misconception? Newton found this context appropriate to explain “true weight” against the “commonly understood” weight as a quality disappearing in water. He was the first who split the weight concept in two:

> . . . bodies placed in fluids have a two-fold gravity: the one true and absolute, the other apparent, common, and comparative. . . . Those things which are in air, and do not preponderate are commonly looked as not heavy. Those which do preponderate are commonly reckon heavy, inasmuch as they not sustained by the weight of the air. The common weight is nothing but the excess of the true weights above the air. (Newton, 1978, p. 197)

An inaccurate use of weight terms, as when the word “apparent” is dropped in discussion on “weight loss” in applications of Archimedes’ law (e.g., Tipler 1990, p. 341), might constructively resonate with the scheme 3, which exactly reflects one’s own perception of heavity. Students might consistently relate “weight loss” to the gravitational weight definition (Tipler, 1990, p. 83). Does it remind us of the “weight loss” of the kind Newton warned and we observed in Q6?

Weight definition II strongly differentiates floating in water from the state of weightlessness and implies unchanged weight for the immersed body (Table 2).? 

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?This regards the application of weight definition II to the immersed body. In this case, the liquid provides a support (buoyant force) applied at the contact surface. This additional support reduces the scale reading when the submerged body is weighed, but the total support force (the water plus the spring) does not change. One reveals the weight of the body by adding the buoyant force to the scale reading.
To complete the picture, we elaborate on another student’s understanding of the role of the medium. It is related to scheme 3 as the resistance or friction force, exerted by the medium is seen as nongravitational contribution to the weight in air (6-6) and in water (7-2, 7-4), which reduced the weight of the object (7-3). Though inappropriate in any formal weight framework (friction force does not contribute to scale reading in static weighing), it was shown by about 20% of students. This view can be identified with the mechanism of medium resistance to virtual motion, or potential falling. Scheme 3 plus scheme 1 relate this logic to weighing results and weight. Here we can recognize Aristotle’s idea as presented by Galileo:

Aristotle says “... that one must compare the heaviness of the body with the resistance to division of the medium, because if the power of the heaviness exceeds the resistance of the medium, the body will descend, and if not, it will float.” (in Drake, 1970, p. 168)

Q8 and Q9 were designed to exclude scheme 2 (by highly insignificant distance dependence); however, it was still shown, though less frequently. Once unconditionally combined with scheme 1, scheme 2 implied weight alterations in all cases of elevation or falling (8a-1, 8a-2, 9b-1). Scheme 3 (additional force contribution to weight) was also notably shown in claims of contribution of friction (8-5) or other force (9-2) to weight. Thus, Q8b was discriminated by many students from Q9b, because of a “subtle” difference in scale reading (despite uniform velocities in both cases). Indeed, a closer look would reveal the difference due to the air friction which reduces the weighing results in Q8b (8-5).

Scheme 5 of weight knowledge was observed with regard to the accelerated movement. Acceleration (9a-3), speed (9b-2), or movement (9a-4) were seen as directly influencing and sufficient to justify predictions of “zero” (8a-4), “decreased” (8b-6), or “increased” (9a-3) weight. Subjects persistently avoided explicitly using two weight concepts (scheme 0). Some of the responses could be interpreted as tacit use of either apparent weight or true weight, but the interpretation was exclusively reserved for the investigator. This phenomenon might also have a psychological origin, a subconscious attempt to cover confusion and vacillation of intuitive inferences.

Schemes 1 and 2 are easily recognized in Q10 data (Table 4). Their implications are extremely pronounced in the predictions of the contribution of the Moon’s attraction into the body’s weight as registered by a spring balance on the Earth’s surface, and even in predictions of unchanged weight when solely justified by the smallness of the effect. Moreover, undesired implementations of these schemes were registered when the tides phenomenon was brought as a supporting example (10-1). We observed intelligent students bringing forward this mistaken argument, manifesting the same shortcut between weight and weighing results (scheme 1). Many students suggested vectorial summation of gravitational attractions, which might fit the definition of the true weight, but is not relevant for the scale reading.\footnote{There will be no influence of the Moon on the scale reading, as the weighed body and the spring scale (and the investigator on the Earth) are all together in a free gravitational movement relative to the Moon (free fall). This case is an illustration of the claim that the measuring device does not measure the gravitational force itself. When influenced solely by a gravitational force, the scale shows nothing.}
Trying to understand the problem one might examine a psychological influence of the gravitational weight definition of the form it appears in some physics textbooks (Sears et al., 1987, p. 74; Young, 1992, p. 319).

The weight of a body is the total gravitational force exerted on the body by all other bodies in the universe.

Though not all textbooks convey this extreme generalization, one can take it as a legitimate generalization of the gravitational weight definition. We do not discuss here the puzzling nature of this definition, which in terms of physics, or astrophysics, is questionable converging and has no practical value. Instead, we focus on its possible misleading potential when literally interpreted (scheme 1) as an operational guidance to account for weight within scheme 0. Definition I did not encourage students to perform any analysis that could expose other factors which make scale reading different from true weight. The state of weightlessness in a free gravitational movement relative to any celestial body is where the didactic failure of the gravitational weight definition is most obvious. To further illustrate this point, one can suggest a hypothetical moon with greatly increased (four orders of magnitude) density. In that case, the quoted weight definition would imply zero weight on the Earth's surface, while the result of on-ground weighing would remain exactly the same as it is now.9

Another didactic decision, to limit the application of weight exclusively to the on-ground environment (10-2) is not appropriate either, as losing universality, desirable for physical concepts. Bar et al. (1994) reported on weight belief of younger children (9–13 years) that weight does not extend beyond the Earth's vicinity. Our students showed this belief both with respect to the Earth (10-3), or the Moon (10-4), but much less frequently.

Q11 and Q12 were intentionally provocative to probe derivatives of weight knowledge. As previously mentioned, weight confusion commonly increases when students try to apply the weight concept to a celestial body as a whole. We classified the opinions shown as being of indicative significance. To account for the puzzling assertion of Q11, students chose:

S1—to break the weight–gravitation identity. (11-1, 2, 3, 4)
S2—to exclude the case from those in which weight could be measured. (11-5)
S3—to identify weight with an inherent (scalar) characteristic of a body (mass?). (11-6, 11-7, 11-8)
S4—to include interaction with other objects. (11-9)
S5—to modify (extend) the weight definition by introducing a “relative weight.” (11-10, 12-1)
S6—to break the symmetry of gravitational interaction. (11-11, 12, 13, 14, 15, 16, 17)

Each of these indicates an incorrect and undesirable (sometimes, highly undesirable) result of the educational process. Thus, S1 shows a spontaneous break of the weight definition provided by the instruction. This “rebel” conforms to the notions of

9Of course, the Earth–Moon system would look entirely different in this case and the Earth would be called a satellite of the Moon.
the constructivist learning theory (von Glaserfeld, 1992). $S_1$ indicates a commitment to the operation (weighing), quite obscure in the case of a planet. $S_2$ fits the tenet of operationalism regarding the unique method of science (Bridgman, 1952). The $S_3$ view exposes the “falling back” to the mass–weight identity (scheme 6), strongly persistent and commonly treated (e.g., Leyden et al., 1988). $S_4$ represents an attempt to obtain weight as resulting multiple contributions (quite in accord with the quoted definition). $S_5$ resembles the ideas to modify the weight definition in order to adjust it to the tactile intuition of the measurer (“weightlessness is real”: Iona, 1987; Keller et al., 1993; French, 1995). $S_6$ reveals damage to the recently acquired knowledge (gained with “friction”: Brown & Clement, 1987; Minstrell, 1992). Those students revised the most fundamental principle—a mirror—symmetry of force interaction, Newton’s third law. The fact that one third of students were nonrespondents in this task also indicates a conceptual vacillation.

Students’ ideas violating the weight–gravitation identity are consonant to very old ideas of science. Thus, “weight is not gravity” or “weight is mass” are reminiscent of the schema, introduced by Empedocles and adopted by Aristotle, and held until the seventeenth century. Weight was defined there as an inherent property possessed by objects in the sublunary world. The vicissitudes of material bodies were seen not due to their relations to other objects but due to their own character, their nature (Dijksterhuis, 1986). Aristotle wrote:

> The same holds, consequently, also of the matter itself of that which is heavy and light: as potentially possessing the one character, it is matter for the heavy, and potentially possessing the other, for the light. (De Caelo, 312a, 18)

Nowadays, this scheme conforms to the everyday use of weight as one of objects’ characteristics (as shape, elasticity, taste, etc.). As such, it is employed in our colloquial activity (“body’s weight”). Still, in science, standards (etalons) of mass are called “weights,” and in textbooks we learn about “atomic and molecular weights,” instead of masses (Bueche & Wallach, 1994). In students’ knowledge, this belief frames scheme 6, which, of course, contradicts formal instruction. The persistence of this view is due to its strong psychological background stemming from the perception of heaviness (proportional to mass). Indeed, as far as the on-ground state of rest is concerned, such as generic weight characterizes objects well enough for a lay use. This can explain why Empedocles, Aristotle, and Euclid defined weight in early scientific schemata as one of the fundamental qualities (Sambursky, 1987).

Responses to Q12 confirmed the weight—mass confusion (scheme 6) when a planet is considered as a whole. Possibly guided by the discussed weight definition, some students suggested the weight of planets to be a net attraction force of other celestial bodies (12-1), which could not go beyond a declaration. No students claimed that the Earth’s weight was granted by the Moon’s attraction and vice versa (the supporting figure showed both planets side by side). Possibly, this confusing inference, yet logically legitimate in the framework of the gravitational weight definition, would be a reductio ad absurdum, traditionally used by science practitioners to discard implausible claims (Losee, 1993).

Finally, an illustrative example of alternative apprehension, constructed upon the gravitational weight definition, comes from Jules Verne. In one of his famous novels
he discussed the great discovery of Newton’s law of gravitation. When he picturesquely described the astronauts’ experience, on their way to the Moon, in a shell solely under the influence of the gravitational force, he practiced only one weight concept (scheme 0). According to that description, astronauts experience (scheme 1) a gradually decreasing weight (scheme 2), strictly according to Newton’s law, until at some point between the Earth and the Moon, where gravitational forces compensate, they experience, just for a moment, a state of weightlessness. Proceeding from this point, they gradually gain back their weight, mainly due to the Moon’s attraction (Verne, 1970, pp. 290–293). It is difficult not to see the striking resemblance of the logic exposed by Verne and that shown by our students, trying to sum gravitational interactions to account for weight and to explain weightlessness (Q1, Q10, Q11, Q12). Scientists face a serious problem trying to estimate the sum of all gravitational forces, to check the interpretation of inertial mass as a result of interaction between the object and the rest of the universe—Mach’s hypothesis, which cannot be tested at present (Sciama, 1969; Harrison, 1981).

CONCLUSIONS

In this study, the analysis of the data of an intensive, though single, test showed that in a number of ways students’ operational knowledge of weight might not conform to the particular instruction currently employed. The understanding of the gravitational definition of weight and its relation to the results of weighing (scale reading) presents a serious problem for students in high school and college. Students’ postinstructional knowledge can be represented in terms of cognitive schemes which include a reinterpreted gravitational weight definition interwoven with intuitive beliefs.

Moreover, the advanced instruction (AP course), applied to a minority of the student population, often does not resolve the confusion around the weight idea, and considerable perplexity remains. In particular, the advanced-instructed students poorly assimilate subconcepts of “apparent” and “true” weights, that were introduced to reconcile the gravitational weight definition with the weighing procedure results and the tactile perception of weight. Instead, many students employ a single, flexible weight concept (scheme 0), which they adjust to a particular context, weighing results or perception of weight (scheme 1). Among the study factors assessed that influence students’ knowledge are: location (scheme 2), environment (schemes 3 and 4), and motion of the weight detector (scheme 5). When an object is considered abstractly (as in an astrophysical context), weight is often identified with a characteristic quality possessed (scheme 6).

The assessed knowledge about students’ beliefs testifies for the integrative use of the mentioned schemes in various combinations depending on the specific situation. There is evidence to assert that, when a situation is considered in terms of weight:

- Students apply their concept image seemingly molded by a tactile experience, in particular, how heavy things are for a potential lift or support. This
intuitive operational understanding is directly related to the perceived pressing force and might result in the widely observed logic shortcut: weight → results of weighing (scheme 1).

- Students address their informal knowledge, acquired through the ubiquitous exposure to the social environment (movies, books, TV programs, etc.). This scientifically unorganized information (especially regarding satellite and on-Moon environments), and particular experiences (such as “weightlessness,” “over-” and “under weight”), are acquired before any formal instruction. They are both interpreted conforming to, and cause, the construction of the intuitive schemes of tactile origin.

- Students unconditionally apply the “simple” idea gained from the school instruction, which identifies (not only equates) weight with the gravitational force. The dominating component of this “gravitational” knowledge is the assertion about distance attenuation of the gravitational force, formally represented by

\[ F_{\text{grav}} = G \frac{m_1 m_2}{r_{1,2}^2} \]  

(scheme 2). An astrophysical context, the mistakenly interpreted second-hand space experience, seemingly reinforces this scheme. Usually, the knowledge of Newton’s gravitational law is not accompanied by the awareness of its stipulating constraints (such as nonextended masses, action at a distance nature, \( 4 = 0 \) inapplicability).

These inferences facilitate our claim of the existing discord between the concept definition of weight, provided by common instruction, and the concept image of weight, virtually constructed by students. This mismatch between the formal scientific and private alternative knowledge manifests itself in such shortcomings of understanding as:

- Extremely disproportional functional dependence of gravitational force on distance, which enables students to account for the state of weightlessness.
- Readiness to admit multiple contributions to weight from different nongravitational sources (pressure, inertial force, etc.).
- Inferences that the medium (vacuum) causes, influences, or transfers the gravity.

Physical situations such as accelerated motion, immersion in liquid or gas, and free motions in a gravitational field are especially suitable for revealing students’ alternative ideas about weight. The hybrid knowledge which results in the formal instruction, students’ difficulties, hesitations and misconceptions in the weight–gravitation domain might be symptomatic of the imbedded ambiguity (if not inconsistency) of the gravitational weight definition. Some examples of a misleading potential of the gravitational weight definition were discussed.

The knowledge students construct, is often closer to operational weight definition II. In terms of Figure 1 it means lesser “distance” to the formal knowledge within the framework of definition II. This might suggest a pedagogical preference of the instruction that conceptually separates weight as a contact force, directly measured in weighing, from the gravitational force acting at a distance. Operational weight defin-
tion II could simplify weight—gravitation instruction and avoid some of the student difficulties mentioned. It is also beneficial for students’ studies, beyond high school curricular (the framework of inertial forces, general relativity, etc.).

When one studies the knowledge on weight, which children spontaneously construct, and that which students construct after being instructed in physics class, much similarity with the evolution of the understanding of weight in science is observed. This similarity can be useful as it elucidates (in the constructivist sense) the common epistemological origins of the weight concept either defined by physicists in course of history of science or presently constructed by an individual.

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