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WEIGHT and GRAVITATION are different concepts

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WEIGHT AND GRAVITATION ARE DIFFERENT CONCEPTS

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ABSTRACT

The approach to equate two fundamental concepts, weight and gravitation force, is a simplified definition of weight currently adopted in introduction courses of physical science. It appears that this definition can mislead students in their interpretation of a state of weightlessness they observe as a reality inside a coasting satellite. The reported study, which covered intermediate - high school students, students of a pre-academic studies university department and pre-service teachers, shows that post-instructed students kept to distinguish weight from the gravitational force. The strategy of equating the two concepts - weight and gravitation force is interpreted as causing a series of misconceptions related to the state of weightlessness and is interpreted as provoking wrong inferences about the gravitational interaction. The alternative definition of weight might be more effective as a teaching strategy stimulating the students' correct understanding of physical phenomena.

INTRODUCTION

Science research contributes a lot in search for the most effective way to promote learner success in the complicated process of science education. Research educators discuss the content of the curricular, the order in which its items should be taught, the time sharing between them, the strategy used in their presentation (Harlen 1977, Driver and Oldham 1986). In much less frequent cases the science educators have a choice of a very different character: they may choose the kind of definition to teach a specific scientific concept. The concept of weight provides such a case (Galili 92, Maarschalk 1992). The importance of this specific case is largely enhanced due to the importance of the weight concept and the concepts usually related to it, such as weighing, gravitational force, forces in general, etc.. They are included in any science curriculum all the way - from the elementary-intermediate-high school to the college and university. These are basic scientific concepts and the way students comprehend and operate them is of crucial importance for the success in the learning process (McDermott 1975). Constructivist approach to science teaching-learning process further legitimated this claim (Driver 1981, Driver *et al.* 1985).

From the other side it was reported not once that weight concept presents a special problem for its understanding by students of all ages (Gunstone and White 1981, Watts 1982, Ruggiero et al. 1985, Mayer 1987, Noce et al. 1988) and teachers themselves (Kruger et al. 1990). Physics teachers are aware of students' problems with the concept (Berg and Brouer 1991). The topic of weight attracts a special attention of physics educators (Taylor 1974, Iona 1975,1987,1988). We have been performing a many-fold study on the subject of the teaching of weight. Among the goals of the study are to document the relevant students' conceptions, to trace their formations and to match them with the ways the weight concept is presented in science classes and textbooks. Here we present a fragment of this study which is important by itself. We studied the students understanding of the physical state called in physics "weightlessness". This interesting physical phenomenon always magnetized people mind (Verne 1970) but appears to be not simple for students' understanding. Hence, it deserves a lot of pedagogical attention (Stables 1973, Mosqueira G. 1973, Bachmann 1984) and possesses a reach soil for testing students' understanding of weight and gravity (Galili 1993). The final conclusions about the preferable way to teach weight should take into account the whole spectrum of considerations which should include the aspect of match with the modern physics approach, methodological considerations as well the views of the science philosophy on the subject. Only such research based recommendations for the science educators might improve their efforts in promoting students' better understanding of sciences in general and of physics specifically .

THE CHOICE IN THE WEIGHT DEFINITION

Physics teachers are aware of the dichotomy in possible ways to define the concept of weight and could choose (in theory![1]) between the two ways of

[1] In practice most of the physics textbooks available in English (e.g. Halliday and Resnick, 1988) adopt the weight definition we labeled lower as definition I. Few present the subject according to the definition II (e.g. French 1971, Marion and Hornyack 1982).

teaching (Figure 1):

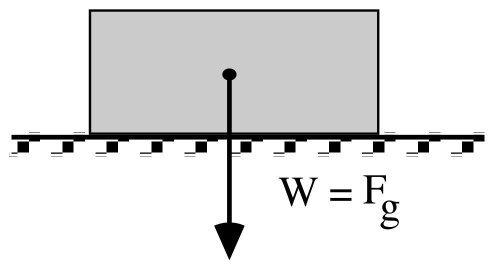
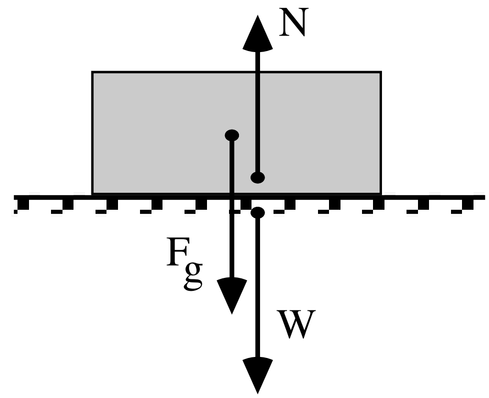
DEFINITION I: Weight, **W**, is another name for the gravitational force, $\mathbf{F}_g$. (Weight force and gravitational force are synonyms.)	
DEFINITION II : Weight is the result of weighing. Then, weight is the force exerted by something against support (or pivot) - **W** and is quantitatively equal to the contact, elastic, normal force exerted by the support (or pivot) on the object **N**.	

Figure 1

If the framework of the definition I is adopted, then the following extension is introduced later on in the textbooks of college-university level. The weight concept is then split into two additional concepts: the first is a "TRUE WEIGHT", which means $W_T = F_g$ and the second is an "APPARENT WEIGHT" which means $W_A = N$ and this way coincides with the weight definition II. This distinction is sometimes not made at all, in books of the introductory level (e.g. Leiden 1988), and sometimes, it is made only as a part of more advanced learning material, usually, in trying to make sense in accounting for the phenomenon of weightlessness inside a satellite (e.g. Faughn et al. 1991).

Our intention is to show that this is not an academic discussion of semantic importance but the problem which deserves more attention.

RESEARCH SAMPLE

This study focused on the knowledge of students which were exposed to formal instruction on two educational levels. To increase the reliability we comprised the sample in both levels of few subgroups recruited from different schools, a group of a teacher college students and a group of students in the pre-academic studies university department. This way we smoothed the influence of factors of an occasional character (like teacher's personality) which could causes some distortions in the data.

First educational level group, 'EL-1', contained 34 students (aged 14-15) from four 9-10 grades of two ordinary urban high schools. These students are expected to have obtained only basic general knowledge about weight and gravity concepts from their studies in General Science classes in elementary and intermediate (Junior High) school. ('Mass and Weight' unit is included in Israel in the study program of the intermediate school). Though the acquired formal knowledge is limited on this level, the other, alternative sources of knowledge could be noted but not evaluated (at least in this research). They include: personal sensational experience, everyday language, books, parents, TV-programs and others provided by the environment in a modern society. Hence, the students of this group appeared to exploit a mixture of views, not precisely defined, which could be labeled as 'plural' knowledge on the subject.

Students of the second educational level group, 'EL-2', were novice knowledge students expected to possess the formal, ordered views after the standard classical mechanics course.

86 students of 11-12 grades (aged 16-17) were recruited from six classes in three different high schools in the same city. Four classes were from the ordinary schools and two classes were from a prestigious school of the city.

The subgroup of 28 Teacher College students (adults of 22 and older) were pre-service teachers of technological disciplines (electronics, computers). The pertinent material from physics curricular was studied by them at least twice. First, during their high school studies and, for the second time, during their first year of their training program in the college.

The next subgroup was 27 University Pre-academic Study Center students (adults of 22 and older). They were enrolled to the special one-year program to upgrade them for the academic studies (they never studied formal physics before). They were taught in a one-year conceptually oriented physics program.

It is of special importance for this study to note that the weight definition, usually adopted for teaching in Israel high schools colleges and universities, is the definition labeled by us as approach I.

TEST, RESPONSES, INTERPRETATIONS

A paper and pencil test was administered to all sample groups. We bring here some illustrative data, accumulated both in a pilot study with the similar sample, and in the following, more extensive investigation with more various physical situations probed. In all questions we aimed to collect information on students' operation with weight concept in different physical situations.

The first question we consider here was also included in a pilot study (Galili 1993). Students were queried about weight and gravitational forces experienced by an astronaut inside a coasting satellite (figure 2a). The accumulated answers distribution is presented in figure 2b. The responses were classified in minimum number of the main categories:

'G-yes, W-yes' gravitation and weight both are experienced by the astronaut;

'G-yes, W-no' the gravitation acts on the astronaut, but weight is not;

'G-no, W-no' the gravitation force and weight are both absent or negligent;

'G-no, W-yes' the gravitational force does not act on the astronaut but weight does;

'G=W decreased' The gravitational force and weight, being the same, decrease with increasing of the distance from the Earth.

The fifth category was not exclusive with others. It incorporated the cases when students explicitly commented about the weight and gravitational forces decreasing with the distances from Earth as the reason to the specific forces reality observed in the satellite.

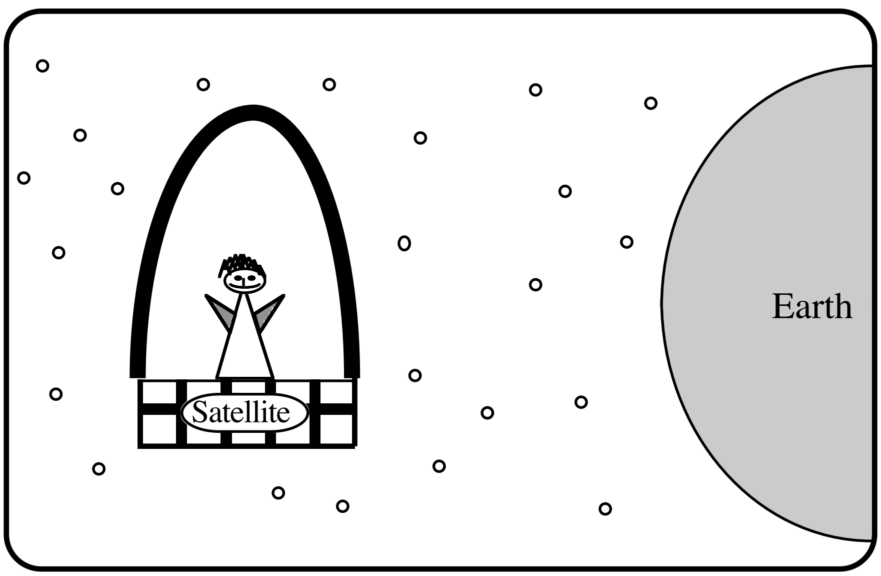


Figure 2a. Coasting Satellite. Task supporting figure.

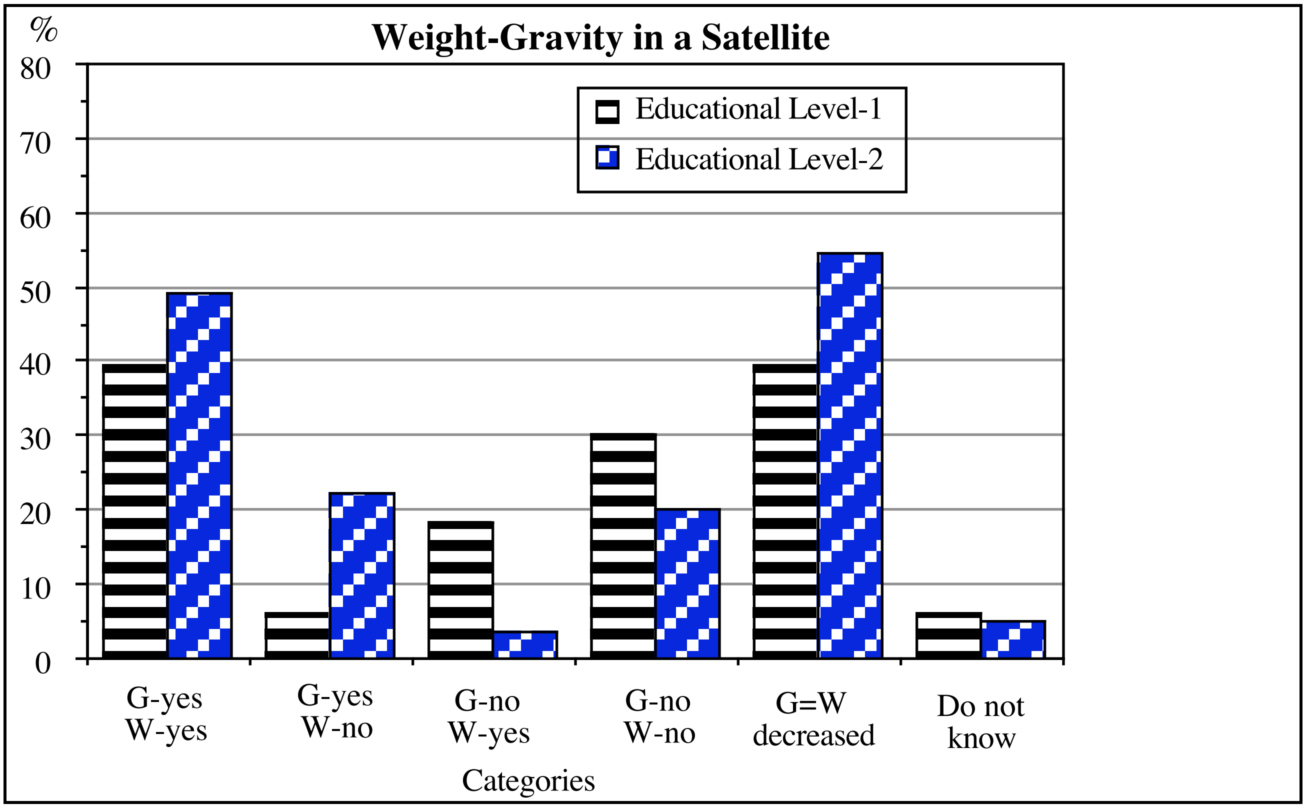


Figure 2b. Students' responses to the Coasting Satellite task

The answer expected according to the weight definition I should be 'G-yes, W-yes'. This answer was given only by 40-50% of the students. Others answered in a different way. An indicative answer was the "G- no, W-no" which discarded both, the weight and gravitation. One might speculate that the origin of the answer was an intention to explain the observation of weightlessness state, known as the state in which astronauts float inside a satellite. This intention protruded from the explicit comments of those students though gave the correct answer "G-yes, W-yes" but supported it with a comment: "They [weight and gravity - I.G.] both exist, but very much diminished because of the huge distance...". All answers, which included a similar kind of explicit comment, were included in the category "G=W, decreased". That is why the extent of the misconception is even higher and exceeded 50% in the educational level-2. Category "G-no, W-yes" mostly appeared at the lower educational level and might present a vestige of the pre-instructional students' view which equates weight with mass and prescribes it to the inherent properties of a body. By the way, it is quantitatively not far from the definition of weight as a product "mg". An interesting documented answer was "G-yes, W-no". This answer coincides with the weight definition II. We can speculate that if this was not the way students were instructed in their class, it might reveal an intention to follow the intuitive understanding of weight as a measure of heaviness. Then, the observed floating things in the weightlessness reality induces a kind of a rebellion against the formal instruction.

To further specify the information about students' interpretations of weighing results inside a satellite (Figure 3a) we asked similar questions for the case when the weighings were performed on an imaginary tower (Figure 3b) on the same heights of the satellite trajectories: 100 and 200 km.

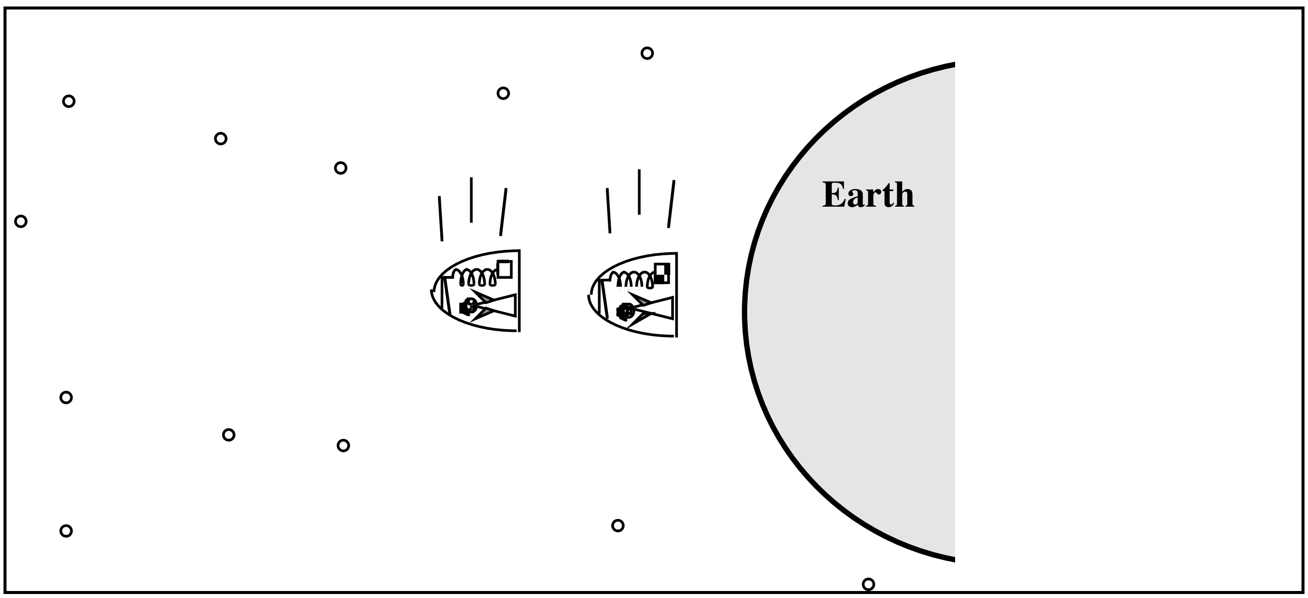


Figure 3a. Weighing in a Satellite

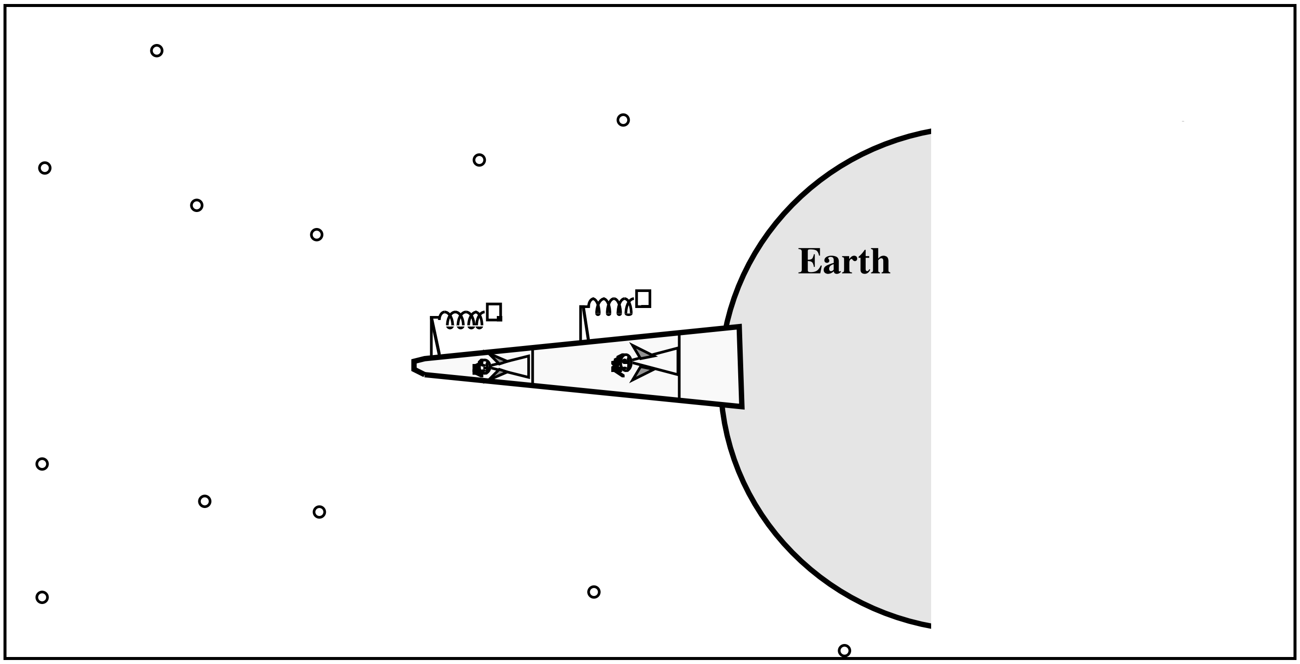


Figure 3b. Weighing on a Tower

Categories ⇒	No weight changes		W=G height changes		Zero Weight-Gravity		No Answer /Do not know		χ^2 and p for df=2	
Educational **L**evel ⇒	EL-1	EL-2	EL-1	EL-2	EL-1	EL-2	EL-1	EL-2	EL-1	EL-2
Q2a Satellite	5.9	9.0	**67.6**	**60.0**	20.6	25.4	5.9	5.7	45.7 <0.001	148.4 <0.001
Q2b Tower	23.5	16.5	**50.0**	**64.0**	5.9	6.8	20.6	12.6	7.8 <0.05	69.3 <0.001

Figure 3c. Percentage distributions of students' answers about Weight in a Satellite and on an imaginary Tower and their χ^2 evaluations.

The distributions of students' answers (Figure 3c) left little room for guesses. Both distributions (satellite and tower cases) could be classified as not occasional with the very high level of confidence (p<0.001 and p<0/05).

Furthermore, the significant overlay of both distributions leads to the unavoidable assessment that many students see both physical situations as similar and prescribe the weightlessness to the effect of the reduction of the gravitational force with the distance from the Earth. At the same time (!) only a minor group of the students (still, 20-25% in a satellite) mentioned precise "zero weight" as their answer. To our mind, this indicates their adherence to the definition of weight as equal to gravitational force. The weightlessness (they observed so many times as the Skylab reality) is then interpreted by them as a negligently small but not zero weight. Why the weight is small then? Two factors (both or one of them, in each individual case) were important to our students. They were:

1. *the absence of air* (we do not bring here the correspondent results of our test regarding the influence of this parameter, but a reference could be done to the studies of Minstrell (1985) or Ruggiero et al. (1985)). This parameter is stronger articulated at earlier ages and lower educational level.

2. the *"big" distance* to the Earth. This factor took the whole game.

An additional evidence of this inference could be provided by another question, which probed students understanding of weightlessness state when it takes place much closer to the Earth surface. A freely falling elevator (Figure 4a) was the famous Gedankenexperiment of Albert Einstein. This fact seemed to be unknown to our students. Figure 4b shows the distribution of students' responses. The question asked about the forces reality in this physical situation and asked for the description of bodies' behavior in it. Less than one third of the groups at both educational levels mentioned gravitational force as a sole active force. Very few predicted the weightlessness (about 7% of EL-2 group). A few predicted weight changes. The confusion was rather obvious: some showed an additional force, besides the gravitational and elastic (an inertial force?), others kept the elastic force active also during the free fall. Few predicted the retarded movement of the passenger relatively to the elevator box. This last understanding matches with Aristotle's framework in which "the heavier the body is the faster fall takes place". All this reveals a confusion more than a misconception. Our speculation in this case is that the situation of a falling elevator is much less familiar (today!) than the situation of the coasting satellite. And the weight definition I equating the gravitational force with weight, did not stimulate the forces analyses which could bring students to the prediction of a special kind of state which we call 'weightlessness'.

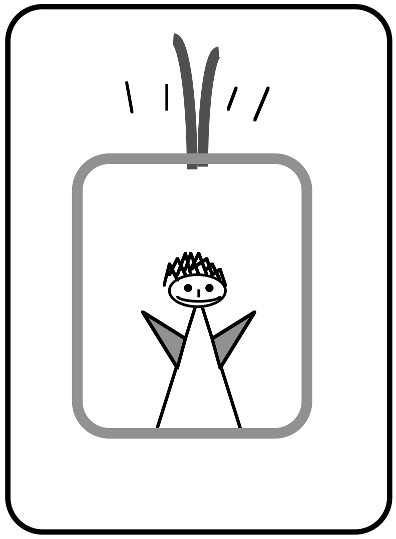


Figure 4a Free Falling Elevator

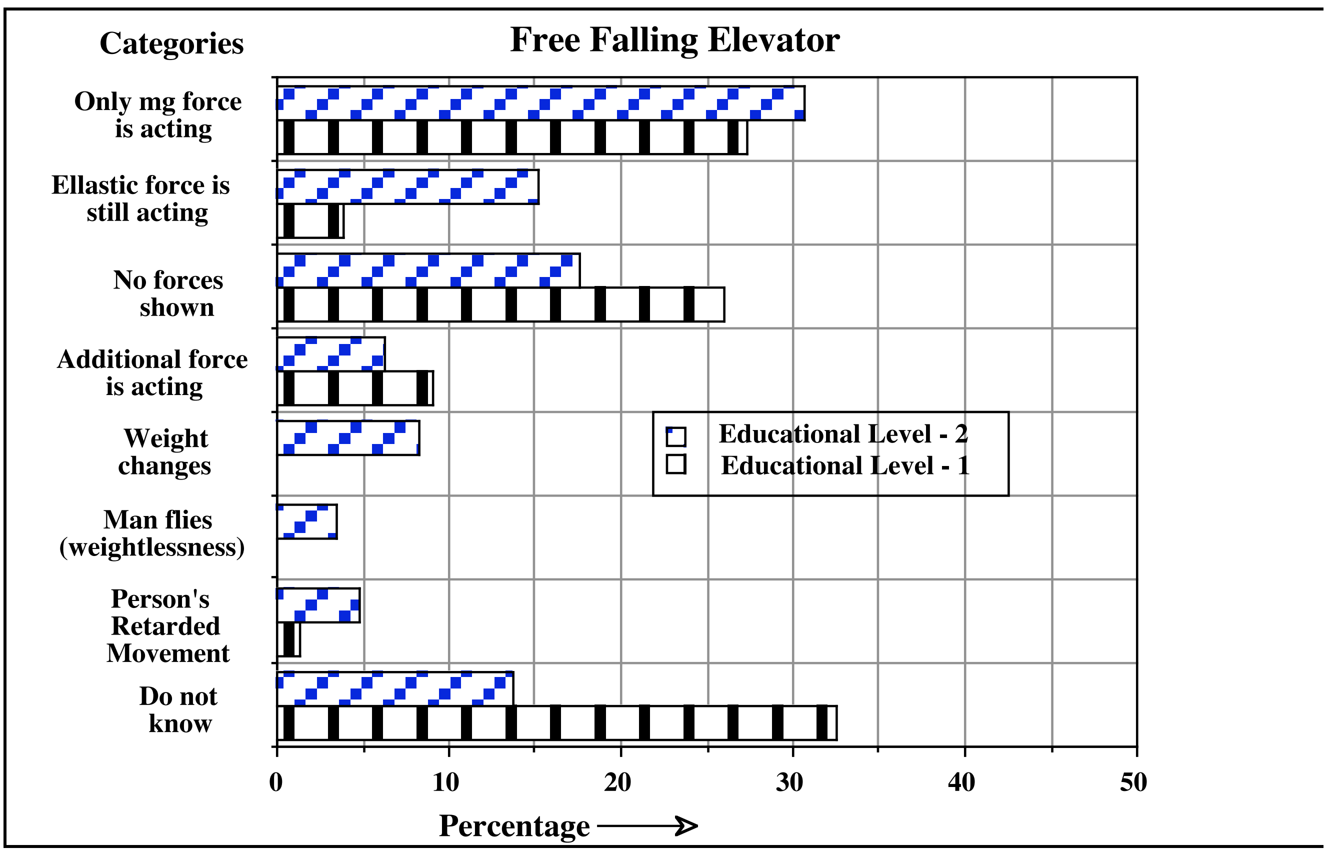


Figure 4b

All together, the discussed responses to the three successive tasks we brought here, show the paradigm of students thinking: The weightlessness is comprehended as a function phenomenon of a location ("big" distance to the Earth) or/and an environment (an empty interstellar space), but not of the motion state. This understanding, of course, contradicts the Newtonian mechanics canons.

POST-EXPERIMENTAL SPECULATIONS

We have presented here a fragment of a broader study on students' operation with the weight concept. This fragment contain the information dealt with students' understanding of weightlessness. We interpret the documented shortcomings of the students' knowledge as systematic, caused by the alternative framework of understanding. That is why we should classify these as misconceptions and not just mistakes. An integrated analysis of a number of test questions permits the inference about the possible misleading potential of the currently adopted by many physics textbooks weight definition I. Weight definition I, in its simple reading, equates the gravitational force with weight. The problem we see here is not (only) a quantitative mistake made due to the influence of motion (falling and rotation) and is not of a semantic character. The problem is methodological. The way weight is measured (usually through a spring balance reading) provides the information about the gravitational attraction only indirectly. The inference students made and mistakenly generalized that the scale reading is equal to the gravitational force towards the Earth is simple (and correct) only in the specific situation - a rest (or constant speed relative to Earth) state. Even then, it is not precise due to the Earth rotation. It is true that the measurement made on the rotating Earth equator and the imagine measurement on a non-rotating Earth will be relatively different by a diminished factor of 1/290. However, in the learning process this discord appears to be a matter of a principle significance as it reflects the fact that we *measure* an elastic force and not the gravitational one. As we observed in our research, a shortcut made between the weight and gravitation does not encourage the students to consider the physical situation from the point of view of dynamics laws. Students easily and mistakenly extrapolate the state of rest to the state of rest relative to the laboratory, which itself could move with acceleration. Some of the students showed the comprehension of weight as an inherent property of bodies invariant to any environment change. Actually, this intuitive view is much closer to the mass concept. Other students alternatively interpret the state of weightlessness or what they observe as a satellite reality. Trying to make sense of this observation, to match it with their oversimplified understanding of the weight definition I, they mistakenly infer about the crucial role of the atmosphere for the weight-gravitational interaction, or/and they falsely infer about the range of the gravitational interaction. It seems that we can represent the process of students thinking as a "tree" of logical chains. The "tree" starts from the truly observed situation: "Weightlessness is a reality in a coasting satellite", and "grows" through wrong inferences to further related misconceptions, wrong conclusions regarding a whole group of natural phenomena. Some fragments of this tree based on the shown data are presented in figure 5. Each arrow in the diagram should be interpreted as a logical connection between the two statements: the arrow starts from the premise ('if'-statement) and it terminates at the inference statement made by a student ("then"-statement). We showed some of important observed logical scenarios up to three steps long, which seem to us relevant to the topic of this study. All routs terminates with serious misconceptions (partly previously reported) which are more than just mistakes. For example, the chain:

(IF) "Weightlessness is a satellite reality" $\Rightarrow$ (THEN) "It is caused by the huge distance from the Earth " $\Rightarrow$ (IF) "Weightlessness is caused by the huge distance from the Earth " $\Rightarrow$ (THEN) "Weightlessness is never absolute: there is always, at least very small, but finite weight"

terminates with the misconception which should be of primary importance for any physics educator as it contradicts the basic message of the classical mechanics. The same could be claimed about the misconception "Free fall near the Earth is not accompanied with the state of weightlessness". Even the anecdotally looking terminal statement "Only superpowers (or rich countries?) can afford the creation of weightlessness" is not less important for the physics educator as it indicates the existence of other underlying weight-related *physics* misconceptions. All of these misconceived students' inferences were observed by us in the form of comments students made in the research tests and afterwards, during the inevitable post-test discussions in the classroom when a "satellite reality" and other associated topics were the subject of rather vivid discussions.

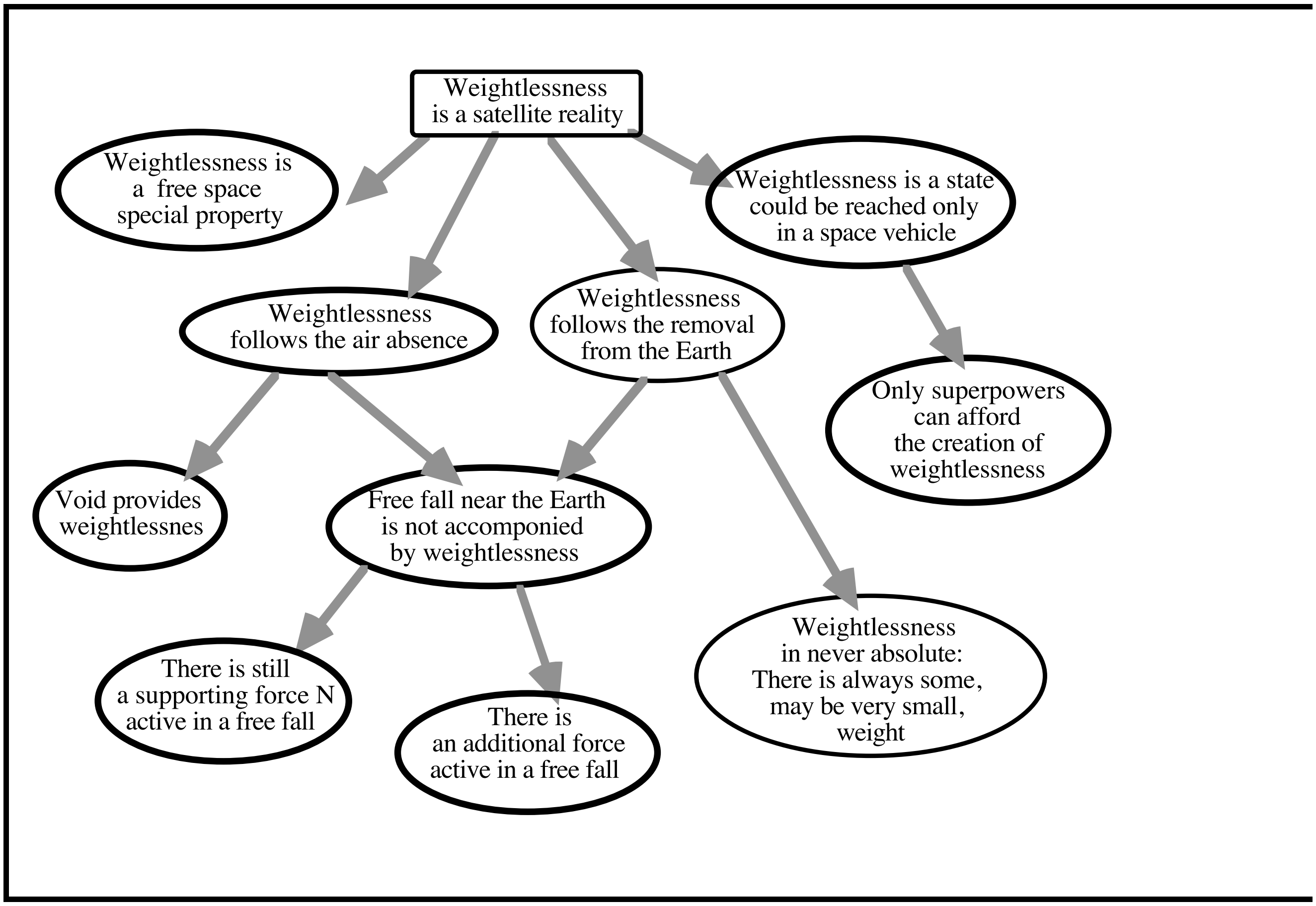


Figure 5. Students' "Tree of logical chains" which presents mistaken inferences stemmed from the observation of a reality inside a coasting satellite.

Another observation seems to us significant. Most of the students, except for a few cases (not exceeding 5% of the sample), did not explicitly use the terms "apparent weight" either in the context of the shown answers, or in a wider context of questions regarding weight and weighing in various physical situations we asked additionally. Slightly more of them used the term "true weight". Colloquially, students sometimes used the term "real weight" but this undocumented usage was ambiguous and could be interpreted as a substitution to the both mentioned terms of a complimentary meaning. It could happen, that the students did use the concept of "apparent weight" operatively (especially those provided physically correct answers) but they did not show this in any way. Even if this assumption is true, there might be a symptomatic meaning of the fact that they avoided the use of this term explicitly. The relatively low rate of the correct answers (in spite of the above average skill level of the participants) might indicate that it was cumbersome for students to differentiate between the two complimentary weight concepts and they just abandoned the complexity of the concept, simplified it back to one - weight. This brought them already to explicit mistakes, as without the extension of the weight definition I into two additional concepts - the "apparent weight" and the "true weight" it (definition I) becomes simply wrong in many cases.

In this study we wanted to exemplify the difficulties students have interpreting the state of weightlessness which they observe as a reality inside a coasting satellite. This misinterpretation causes the consequent misconceptions they might assimilate. All this could be understood as a result of the incorrect application and interpretation of the weight definition I. Moreover, this misinterpretation might be provoked by, or even embedded in the weight definition I. It seems that the adopting of the alternative weight definition (II) which separates the question "what is the weight?" from the question "what is the gravitational force?" and is an "operational definition" (Arons 1984), might promote students' meaningful learning of this important part of science curricular. Only experimental efforts of actual teaching weight according to the definition II might contribute to the more confident and specific recommendations on the issue.

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