Explaining the "at rest" condition of an object

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Consider an object, e.g., a book, at rest on a table. What keeps the book at rest on the table? Typically, in a physics class the instructor will assert that gravity and the table exert equal, but oppositely directed, forces on the book thus keeping the book in equilibrium and at rest. Often the authority of "Newton's Law" is used as justification for this explanation, and the instructor moves on to consider conditions of moving objects, assuming that the static situation is "obviously clear" to students.

This paper demonstrates that the typical explanation is far from obvious to the student. First, students are unsure about the nature of gravity. Some distinguish the pull exerted by the earth from a heaviness of an object tending to make it go down. Many students believe that air pressure is the cause of gravity. Second, the nature of forces and how they can be exerted is "unclear" to students. How can a push or pull be exerted by an inanimate, inactive, solid, and apparently immovable object like a table?

This article describes the results of considering the "at rest" condition of an object with two physics classes at a high school in a socioeconomically affluent suburb of Seattle. In addition to pointing out the nontriviality of the static object situation, the results of my investigation suggest the following instructional factors that apparently aid in the development of the students' concept of force: a) an engaging, free thinking, free speaking social context, in which students are encouraged to articulate their beliefs, b) a juxtaposition of a variety of first-hand experiences with static objects, and c) encouragement to search for the simplest, consistent, rational argument that will explain the similarity of effects in an apparent diversity of experiences. Finally, and perhaps most important, this paper presents an example of a technique for instructing for *concept development*.

In attempts to describe the conceptual understanding of physics students and to identify factors that influence that understanding, discussions were tape recorded. Also, homework papers and pre- and post-instruction tests were carefully read. Thus, the investigation was conducted entirely in the natural setting of the physics classroom.

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Pre-conceptions/alternative conceptions

Prior to any formal instruction regarding forces in the two physics classes investigated, students used one or more of the following mechanisms to explain the book at rest.

Air and/or air pressure may be responsible for helping to keep the object where it is. Many students drew and labeled diagrams that depicted air pressing in from all sides (Fig. 1). For others, air pressure appeared to be acting predominantly in the downward direction. Some of these students viewed the air pressure as helping gravity hold the object down to the table (Fig. 2), but a few (approximately 15%) implied with word and diagram that it was air pressure that was responsible for holding the book down (Fig. 3). "If the air was taken away, the book might drift off." For these students, it appears that gravity is a result of air pressure. A few students also suggested wind or wind currents, probably from the side, could affect the objects (Fig. 4).

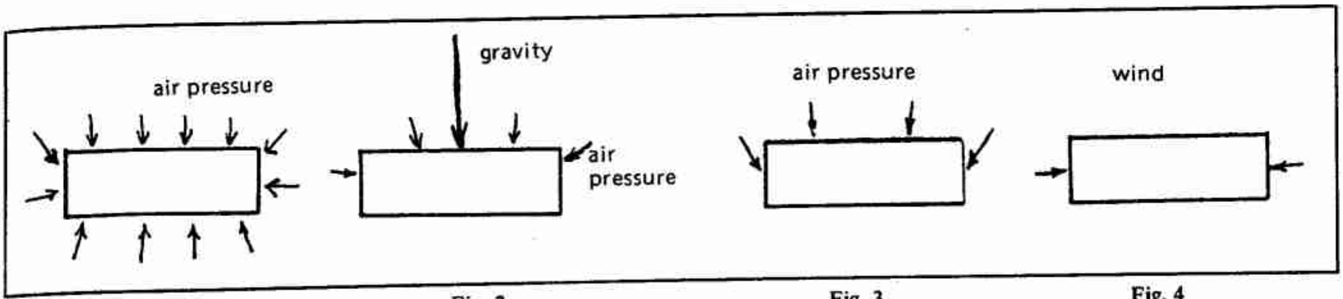

Fig. 1 Fig. 2 Fig. 3 Fig. 4

Gravity was invoked by nearly all the students. Most talked about gravity as an "action at a distance" somehow exerted by the earth. But, in addition to the "air pressure responsible for gravity" confusion, some used gravity more like a property of the particular object, e.g., "gravity is the tendency for objects to go down" rather than as a pull exerted *by* the earth *on* the object. This conception of why things like books go down is at least as old as Aristotle whose explanations involved the tendency for objects made of earth materials to go down to their natural resting place on the surface of the earth. *The table* exerted an upward force in the minds of about half of the students. For the others, "it wasn't necessary" for the table to push upward, or "the table was not capable of exerting an upward push." The table was simply "in the way." This alternative conception has been described by Clement[1] in his work with engineering students at the University of Massachusetts. Since "lack of table force" was the most generally applied "misconception," I attempted to identify factors affecting the change in this conception. The investigation will be described in the next section of this paper.

An occasional student argued that the situation was different if you put the object outside on the ground rather than putting it on the table, e.g., "but . . . outside on the ground, gravity wouldn't be on the book, because it is then already all the way down to the ground" (Aristotle's natural resting place?). Another student used a similar argument to suggest that the upward force vanishes when the object is on the ground. ". . . because I didn't think there was . . . like a table force because the gravity is drawing the object toward the earth, so if it's in contact with the earth, it can't get any closer." When asked if gravity was still acting on it, she responded "Yeah, but not the upward force."

For those who believed the object stayed where it was by a combination of forces, some agreed with the physicist's view that the upward and downward forces must be equal to each other. However, a large number of students believed that the downward forces must total more than the upward forces or "the object would float away." The greater downward force apparently is needed to "hold the object down."

Evidence for development

At the beginning of a particular class discussion, I asked students for their ideas about the meaning of force. The dominant view involved a push or pull. Students seemed to believe that although most forces occurred as a result of direct contact, there were some interactions that seemed to exhibit forces applied at a distance, e.g., "like the magnet."

Next, I introduced the use of the vector to represent each particular force on an object. Since earlier in the course they had used vectors to describe acceleration, velocity, and changes in position, the students were reasonably comfortable with the idea of an arrow representing the direction and magnitude of each force.

A book was put on a table and students were asked to use arrows to represent the forces acting on the book. There were two dominant views. The main difference of view lay with the vertical forces on the object. Approximately half the class believed that gravity and the table were exerting opposite forces. The other half believed that only gravity was exerting a vertical force, "the table was merely in the way." During the rest of the class period, the discussion focused on arguments for or against one of these two views (Fig. 5).

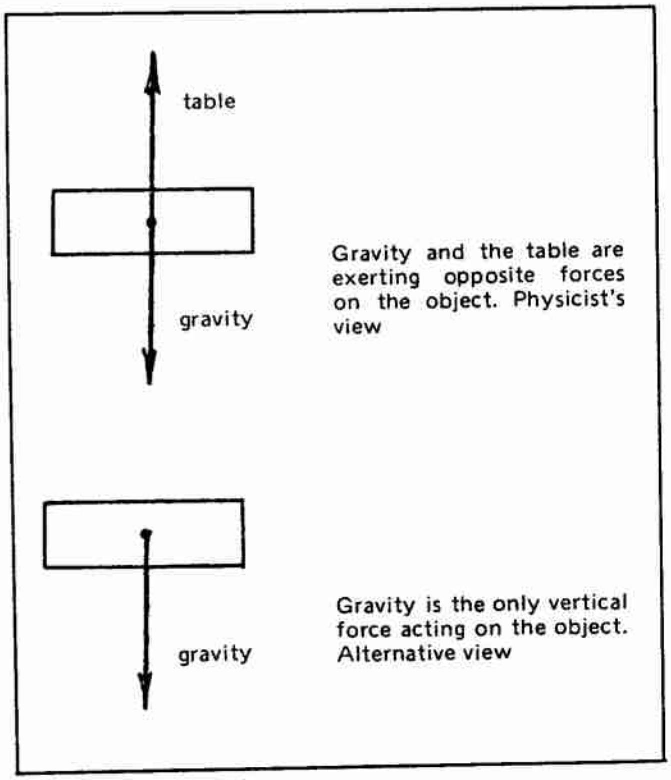

Fig. 5. Two dominant views

I then proceeded through the series of demonstrations that follow: The book was placed 1) on the table, 2) on the outstretched hand of a student, 3) on the hand again, after more books were added to the hand, 4) hanging from a spring, and 5) on the table again, then a beam of light was reflected at a low angle off the table top to the wall, and I stood on and off the table causing a depressing of the table top shown by the movement of the reflected beam. Also, a small plastic ruler was hung from the spring with imperceptible extension of the spring, and finally the book was placed 6) on the table yet one more time. For each demonstration, students were asked to diagram and defend the forces acting on the book. Other than sequencing the demonstrations, asking questions regarding student explanations and justifications, and moderating the ensuing discussions, I endeavored not to instruct the class as to an "accepted answer."

The table below contains an abbreviated summary of the demonstrations, questions, and resulting beliefs of one physics class. After each question regarding forces on the book, I asked students to defend their beliefs, first through a show of hands (a quick poll) then through arguing their beliefs in class discussion. The gradual change in belief (sampled by the quick polls) suggested convergence toward the belief in upward force exerted by the table.

When the other class was ready to study Forces, the same sequence of demonstrations was followed. This time audio-tape recordings were made in an attempt to identify factors influencing change in students' understanding. An abbreviated version of the demonstrations, questions, and a partial transcript of the discussion follows. I found the richness of the ideas articulated by the students interesting and informative.

1. A book was placed on a table top and students were asked to diagram and label the major forces acting on the object (to explain its rest condition). Students were asked first to draw their own diagrams and then to compare their diagrams with those of other class members. Then, the students and the teacher/investigator discussed the various answers.

I (Instructor): What are the forces that you have on the book?

S1 (1st student): The table pushing it upward. (laughter from several members of the class.)

S2 Gravity pushing it downward, and the arrow has got to be bigger.

S3 No, no, they're the same.

S4 . . . Wind current . . . very small.

S5 Gravity, no table force, and air pressure pushing equally from all sides, except I don't think it's pushing equally from bottom.

S6 Isn't air pressure gravity? (interjected)

S5 . . . Also, arbitrary wind forces which could happen in any direction . . .

S7 I had . . . the air pressure, gravity and miscellaneous other forces all equal to the force of the table.

S6 Isn't air pressure gravity? (interjected again)

S1 I have one question – you know George's [diagram], I wonder why the objects were not just sucked through the table by gravity [with no upward force].

S5 Because the table's sitting there keeping it from being sucked, but that's not a force. Because the table is a solid object. Now . . . the molecules of that table are not about to open up and let the object pass through . . .Oh!! That means there is not a force that is acting between the table and the object but there is a force that is holding together the molecules of the table to keep the object from passing through . . . the forces of the air . . . no, I'm wrong . . . in that table from the ground up there are billions and billions of molecules all stacked up so the thing can't go through there, okay, but in air there are billions of molecules but they aren't all solid and packed . . . they're sort of loose. If you open up a bag of flour and drop a spoon into it, it won't go very far into it. But if you take the bag and shake it, all the air goes into it like that, then you drop the spoon . . . it goes all the way to the bottom.

S10 So according to that [referring to the diagram of the table force and gravity in balance], if you were to suddenly take off the force of gravity, the thing would shoot up.

S8 Really, that's what it says.

S3 No, because the force of the table corresponds to the force of gravity. The force of table is

Table I
Change toward force exerted by the table

Sequence of events	Number of students: Believing downward force only	Undecided	Believing upward force by support as well
Discussion of what force is, and introduction of use of a vector to represent it.			
Book on table (poll taken)	14	1	12
Book on hand (poll taken)	13	1	13
More books added to hand			
Book on hand (poll taken)	6	1	20
Book on spring (poll taken)	1	1	25
Book on table (poll taken)	9	3	15
Reflect light beam off table with instructor standing on, then off the table, and hang light weight ruler on spring.			
Book on table (poll taken)	1	1	25

always proportional to the force of gravity.

S9 The greater the gravity, the closer the book gets to the table.

2. The book was placed on the horizontally outstretched hand of one of the students in the class. Again, students were asked to diagram the major forces acting on the object to explain its "at rest" condition.

At first there seemed to be no change in students' view of an upward force, but after stacking four more books on the hand one at a time, more than two-thirds of the class supported the view that the hand exerted an upward force. Two students intimated later that they felt that there was an upward force in the situation with a book on the hand, but they didn't "vote" that way because they thought the answers for "book on table" and "book on hand" should be the same, i.e., consistent. During the discussion, I pointed out that many students had apparently changed their points of view from "book on table" to "book on hand," and I asked "What's the difference; why do so many more believe in the upward force in this situation?"

S2 Maybe he is giving a force . . . because that is not a normal position for him, and he's got to have a force to hold it up. But the table, that's a normal position for the table to be in. It doesn't exert any force.

S13 If you take the book off, his hand's going to go somewhere, but the table, you take the book, the weight off, and it's not going anywhere.

S5 If you keep piling weight onto S's hand then his muscles, the actual energy he's using up here and here (pointing to upper and lower arm) would be exhausted long before the physical bones and muscles would break. Whereas, the only way to get the table to stop holding up what you put on it is to put on it enough weight that it totally collapses. It's not exerting any energy to keep whatever is on it up.

S5 Well, the forces affecting the object are the same, but because it's resting on your hand . . . your hand's involvement in the situation is different from the table's . . . but it doesn't affect the object any differently. The object is sitting on your hand just as peacefully as it was sitting on the table. Your hand is doing more work but that has nothing to do with the object at all.

Prior to this time, the discussion seemed to involve primarily an elaboration of conceptual hypotheses with an occasional logical point from one side or the other. Here, however, S5 and subsequently others began focusing on the similarity of *effects on the book* in various situations rather than on the difference between *objects causing the effects*; a search for consistency of effects began.

S6 Your hand can move up and down but the table is stationary. Your hand can make the object move all around. The table just sits there. It has nothing to make it move up and down and all around.

S4 Your hand has a certain amount of potential strength before . . . if you put too much weight on it, your arm's going to break. So the table has that same amount of potential strength. If you put something that's not real heavy that's not going to break the table, it's not going to use as much strength as it has. It's going to put a force on it, otherwise it would go right through the table to the earth . . . if there was no force pushing up.

I Would the diagram of forces be different when my hand is resting on the counter with the weight resting on my hand? (Instructor demonstrates with book on hand held outstretched versus book on the hand which is resting on the table).

3. The book was hung from the end of a spring.

S3 Oh my gosh!

S5 [Spontaneously coming forward to hold weight supported by spring.] Is it easier to pull it up when it's on the spring than when it's not on the spring? . . . There is definitely a force by the spring, definitely. It is much easier to pick the weight up when it's on the spring.

S8 What if this wire (spring) was completely stretched out until it was one long string . . . then it would be the same effect as the table according to the people who are saying that.

S13 I think that the hand is force and on the table it's not force and that [on the spring] is not force, because once you take the weight away, that contraption isn't going anywhere. If you've got two equal forces hitting each other and you take one away, it's going to take off. [The instructor took the book off the spring which snapped back to rest.] The spring goes back, but the rest of the contraption doesn't . . . if that was stiff wire and it wasn't going to spring back, it's the same thing [as the table].

S8 That's why I don't understand why those people still don't say what they did when they were talking about the table, cuz it's the same effect on the spring.

Several of the students expressed an interest in using *consistent reasoning* across all situations, e.g., "your hand . . . doesn't affect the object any differently [than the table]," or "if you stretch the spring out . . . , it would be the same effect as the table." This reasoning strategy is similar to one of Newton's Rules of Reasoning described in the *Principia*, i.e., " . . . to the same natural effects [static object], we must assign the same causes [similar forces]." The "object on the hand" demonstration seemed to have convinced some students of the existence of an upward force in at least that one situation. The reasoning strategy was then apparently sufficiently strong that they generally inferred an upward force in all situations.

4. A light beam was directed at a low angle of incidence onto the table top and the position where the reflected beam hit the wall was noted. A book was placed on the table, then removed. Then, I stepped onto the table and the reflected beam changed position noticeably.

5. The book was hung on the spring, and then taken off. Then, a plastic ruler was hung on the spring and taken off. With the weight of the ruler, the extension of the spring was hardly noticeable.

By this point in the discussion, nearly all the students in the class supported the view that there must be an upward force to keep the object stationary in every one of the situations. Some of the last holdouts saw the consistency between the spring and table situations but wanted to make a distinction between the case in which the person actively pushed upward on the object with his outstretched hand and the situation when another object was just "in the way" of the book. They felt that force should imply an *action* on the book. They recognized that the effect on the book was identical whether the hand actively supported the book, or the table passively supported the book, but they still had some difficulty with the idea of the resistive support of the table being represented by the word force. It was important to spend the time and effort to help students understand that both the active push or pull *and* the passive support or resistance to motion are forms of what the physicist calls force. (See Arons[2] for corroborative evidence of this difficulty and the importance of treating it.)

Implications for teaching

From this classroom research it appears that there are several things a teacher can do to help students develop a more generally applicable cognitive structure for explaining the "at rest" condition of an object. First, prepare an engaging social context, one in which students will put their thoughts about the situation up for consideration, free from fear of being chastised for being "wrong."[3] If students are graded down for being "wrong" at this stage, this will add evidence to the belief of some students that science is known only through the knowledge of some authority. Encourage expression of the various alternative explanations. Allow the validity of the explanations to be determined in the light of observational experiences and rational argument. Second, juxtapose several instances of an object at rest; on the solid table, on the outstretched hand, on the bendable table or spring or rubber band, etc. My choices for the demonstrations described in this paper were influenced by questions and comments from my students in previous years. These situations were apparently disturbing enough to several students that the students were motivated to seek a resolution to their intellectual conflict. Third, encourage arguments that explore similarity in effects and explanations across an apparent diversity of instances of objects at rest. Encourage a search for consistent explanations of some effects. Finally, allow students to argue for the simplest explanation that explains the most phenomena. With the above activities it appears that the student is more likely to adopt the physicist's thinking regarding forces on static objects.

Given that physics teachers feel pressure to cover considerable quantities of scientific and technological material, is the development of an understanding of the "at rest" condition worth the investment of one class period? A first answer is that it may not take as much as one class period to engage the student, to juxtapose a diversity of situations through which the student could be encouraged to seek consistency and integrate the several "support" situations into "upward force." These factors may be integrated into a mode of instruction other than the one described in this paper. But, given the responses of my students, I would question the effectiveness of a short lecture to change these deep-seated views. It is crucial from my point of view that the "at rest" condition should receive more than just the typical token treatment in the physics class. Students' troubles with explaining the static object do not go away by themselves. Even more important, students who have trouble with the static condition have even more difficulty with dynamic cases such as friction, circular motion, and even uniform motion.[2] While understanding the static condition doesn't ensure understanding forces on moving objects, if students don't comprehend forces on statics, they do not understand forces in dynamic situations. Since much of the physics course (mine at least) involves analysis of various forces on objects, not understanding the static cases will cause problems for those students that will last all year, perhaps beyond. Therefore, one class period spent in carefully laying the groundwork for development of a generally applicable scheme for explaining the "at rest" condition of an object is time well invested.

Finally, one of the more important outcomes of this research is that it is an example of an apparently successful attempt to change students' conceptual understanding. Often we "give" the physicist's concepts to students and we ask them to use the concepts as first principles from which they are to deduce the solution to a problem. At best, we hope for development of conceptual understanding by having students assume the concepts are true while applying them in problem-solving activities. This paper describes instruction wherein the focus was primarily on concept development. It appeared that students did change their conceptual understanding. At the very least, as a result of this instruction, they were more readily willing to hold and use the physicists' view of forces on static objects in subsequent problem solving.

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