Weightlessness and Microgravity

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Ask at random any group of students how far gravity extends and you will find that the majority believe it extends only to the edge of the atmosphere. Ask what would happen to your weight if the atmosphere were to suddenly disappear and you will find that a significant number will say you would float off into space. I have asked these questions repeatedly over the years on pretests in astronomy and physical science classes ranging from junior-high to junior-college level with uniform results. Out of the 80 adults entering my most recent junior-college-level astronomy class, only five recognized on the pretest that gravity reaches to infinity.

Everyone knows that the astronauts appear weightless while in orbit, but very few understand why. The conceptual link between free fall, orbital motion, and weightlessness is difficult to establish, especially when most students have already satisfied themselves that they understand: gravity simply doesn’t reach that far.

In the midst of this confusion, a new piece of jargon has been injected into the educational vocabulary: microgravity. The astronauts talk about Earth orbit as a microgravity environment, so the term “microgravity” is now beginning to pop up in science texts as a substitute for “weightlessness.” Apparently microgravity is “in” and weightlessness is “out.” The term is particularly onerous because it tends to reinforce the idea that weightlessness is caused by the lack of gravity. Microgravity is a meaningful term, but it is neither a synonym nor explanation for weightlessness. Some clarification is in order before launching a new generation of students with a refined set of misconceptions.

**Teaching the Fundamentals of Gravity and Weightlessness**

Three potentially difficult concepts must be conveyed to avoid the most common misconceptions about gravity and weightlessness:

- Gravity extends over all space.
- Weightlessness is a result of free fall.
- Orbital motion is a form of free fall.

Newton’s law of universal gravitation originally grew out of the insight that the force that pulls an apple to the ground is the same type of force that holds the Moon in its orbit. Gravity thus extends far into space. If gravity did not reach to the Moon, the Moon would drift away from the Earth never to return. Gravity must extend at least the distance from the Sun to Pluto to hold our galaxy together. The fact that galaxies are found in clusters shows that gravity must extend across millions of light-years. In Newton’s conception, gravity reaches across the entire universe. In any class where Newton’s law of gravitation is presented in its mathematical form, it should be explicitly pointed out that the force between two objects never goes to zero no matter how large the distance between the objects grows.

If gravity binds the entire universe together, the space shuttle cannot be beyond the reach of gravity and diminished gravity cannot explain weightlessness. As a matter of fact, a man sitting on a tower 100 miles high would weigh 95 percent of his weight at sea level, whereas an astronaut zipping by in a 100-mile-high orbit would be weightless. Weightlessness arises from orbital motion, not from diminished gravity and not from being above the Earth’s atmosphere (another prevalent misconception).

Weightlessness can be related to free-fall by a simple demonstration. Probably every science teacher has done Galileo’s experiment showing that heavy and light objects fall at the same rate. Do the experiment again, but this time make one of the objects a rag doll. Hold a ball in front of the doll’s face and drop them together. Say the doll represents a person in an elevator and someone cuts the cable. Ask what the person would see the ball doing as the elevator was falling. Most students can see that from the falling person’s perspective the ball would appear to float. If you were standing on a scale in an elevator at the time the cable was cut, you, the elevator, and the scale would fall at the same rate, so there would be no force between your feet and the scale. The scale would therefore read zero and you could rightly think of yourself as weightless.

Making the intuitive connection between free fall and orbital motion is the most challenging link in the argument. Free fall is simply motion under the
influence of gravity and nothing else. Free fall can occur even when moving sideways. You can toss the doll and ball sideways together to show that they still fall together and the ball still seems to float. You can discuss connecting a bathroom scale to your feet with Velcro and being tossed sideways to illustrate that you would not be able to record your weight under such circumstances.

**Microgravity**

Let us return for a closer look at the falling elevator. Is there any way to tell that the elevator is in free fall in the Earth's gravitational field rather than in field-free space? The answer is yes. Two objects falling freely both fall toward the center of the Earth, so they come closer together as they fall. Furthermore, there are tidal forces induced in each object since the bottom of the object is in a stronger field than the top. These effects are due to the geometry of the Earth's field and are distinct from the mutual gravitational attraction between the falling objects themselves. Only in a uniform gravitational field would an object in free fall be free of all gravitational effects, but a truly uniform gravitational field is as hard to find as field-free space!

Within the confines of the shuttle, is there any way to tell the difference between orbital free fall and a gravity-free environment? Again the answer is yes. Consider two objects placed side by side. If the shuttle were floating in a hypothetical field-free space, the two objects would remain where they were originally placed. Since the shuttle is in orbit around the Earth, however, each floating object is in its own orbit about the center of the Earth in its own orbital plane. Since all planes passing through the center of the Earth intersect, the two objects will eventually meet. In fact, they will collide by the time they complete one-fourth of an orbit, a little over 20 minutes. If the objects are placed one in front of the other, in terms of their direction of motion, there will be no such effect since they are in the same orbital plane. If the objects are one above the other, however, they will migrate in seemingly strange ways relative to each other because they are in distinct orbits, starting with equal kinetic energies but different potential energies. The eccentricities and periods of their orbits are thus different.

Consider another experiment. An astronaut throws a baseball in the direction of motion of the shuttle. In gravity-free space the baseball would continue in a straight line at a constant speed and never return. In Earth orbit the baseball has been launched into its own elliptical orbit, which, since the ball is moving faster than the shuttle, is a larger orbit with a longer period than the orbit of the shuttle. From the shuttle's perspective the baseball will move forward, rise, fall behind, then drop down to a point directly behind the shuttle in a time slightly longer than one orbital period of the shuttle. If the baseball were thrown in the opposite direction it would appear to fall to a lower orbit, speed ahead of the shuttle, rise, and come to a point directly ahead of the shuttle in a time a little less than one orbital period of the shuttle. These effects are important in shuttle navigation and docking maneuvers.

There is a clear but subtle difference between floating in orbital free fall and being free of gravitational fields. Gravity makes its presence known to astronauts, not by a residual weight, but by strange secondary effects that are not directly related to weight.

**Conclusions**

Is microgravity a suitable topic for introductory science classes? It could be a fascinating topic for discussion in physics classes as an application of orbital theory, provided the concepts are properly understood and presented. On the other hand, is weightlessness an outdated term that should be discarded in favor of a new space-age term? I don't think so. It has a history of conceptual difficulties of its own, but it has the advantage of describing a first-order effect of free fall, whereas microgravity concentrates on higher order effects. If the term microgravity is injected into lower-grade science texts as a substitute for weightlessness, it is bound to bring added confusion to both students and teachers.

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**Tricks of the Trade**

*Editor's note:* Each of us probably has some special "trick of the (physics teaching) trade." You may think yours is too obvious or well known or trivial to justify a full note, but it may be just the sort of technique others would find useful. If you will send us your brief descriptions of such practices, we'll use them as fillers from time to time, or, if we have enough, we'll print them as a collection.

**Light Color Mixing:**

**A Convenient "On/Off" Switch**

We use three vertical straight-line filament bulbs covered with red, green, and blue gelatin filter paper (which we get from a nearby theater supply group) to show students how the three primary colors of light add when they shine on a white screen. Different combinations of lights are used, along with an obstacle that can be used to cast a "shadow" or block out selected colored lights.

One hassle that arises is how to turn the lights on and off quickly and easily while trying different color combinations. At first we did this by plugging and unplugging the lights themselves, but one day while using an empty paper-towel tube as the shadow-maker, I thought to place the tube over one of the light bulbs. It was a perfect fit and effectively "turned off" the light. Of course the bulb will get hot if it is covered for too long. So now we use the three lights with several empty paper-towel tubes, and our demonstration goes quickly and smoothly. This would also work for a lab activity if you have enough lights and filters.

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