〔愛知学院大学短期大学部　研究紀要　第12号　平成16年３月〕──　106～124頁

High School Physics Revisited:

Weight and Mass from a Linguistic Point of View

R. Jeffrey BLAIR

Abstract

This paper explores the distinction between weight and mass in the Scientific Discourse Community (SDC) and relates those scientific terms to the way they are used in the General Discourse Community (GDC). In the process it describes the linguistic complexity of normal word use, tries to discover why high school physics students might find the scientific distinction confusing, and suggests a linguistic solution.

This summer my son came back to Japan from Indiana, where he attends high school. In hopes of getting a headstart on the next year's physics class, he brought with him the textbook (Conceptual Physics by P. Hewitt), and I just could not resist taking a look. You see, math and science were my favorite subjects when I was a student. Although those interests changed at Caltech to such an extent that I graduated as a history major, I still have a fondness for mathematics and its physical applications. As I started to read through the book, the mathematical concepts were not particularly difficult to recall and master. Ideas such as

$$\text{Velocity} \times \text{Time} = \text{Distance}$$

are relatively simple even for an applied linguist or English teacher such as myself. Rather, having been lulled into a scientific frame of mind as I waded into the literature, I found myself mystified by distinctions in terminology — distinctions between scientific terms and their general use counterparts. The difference in the first pair of words — speed and velocity — seemed quite clear. Later when I got to weight and mass, however, the explanation of the distinction between their general use and their scientific use seemed inaccurate and confusing. In this paper I would like to explore the proposed distinction between *weight* and *mass* and in the process discover and describe the *linguistic complexity* of normal word use.

From Quality to Quantity
Scalar Numbers and Vectors

Physics is principally concerned with matter and motion. To describe matter and how it moves with quantitative precision scientists need to be able to assign numbers to the qualities represented by dichotomies such as (a) big and small, (b) heavy and light, and (c) fast and slow. I would like to begin with the distinction between speed and velocity to describe the fast/slow dichotomy because of (1) its clarity and (2) its relationship to acceleration and force — key concepts in the distinction between weight and mass, measures of the heavy/light dichotomy.

In normal conversation people speak about speed and direction separately and use velocity as a synonym for speed without any specification of direction. In physics, however, **speed** is a *scalar* quantity, treated simply as a single number, while **velocity** is a *vector* quantity, usually described as a *series* of numbers that specify both speed and direction. The concept of vectors does not occur in normal conversation, that is with ordinary topics and participants who are not scientists or mathematicians.

Now let us turn our attention to mass and weight. According to Hewitt (1999, 49) **mass** is often *confused* with **weight**. The author defines mass as the "quantity of matter in an object" and weight as a "measure of the *gravitational* force acting on the object". He points out that weight depends on an object's *location*, while mass does not. Weight would be very different on the surface of the Moon (100/6 units) than on Earth (100 units). In any given place, however, weight and mass are exactly proportional to each other. This is expressed mathematically in Newton's well-known equation.

$$F = G\frac{mM}{r^2}$$

Here m and M stand for the masses of two objects. In theory, "every object in the universe attracts every other object" (Feynman, R., R. Leighton, and M. Sands, 1963, 7–1). The force of attraction, however, is so weak that it took more than a hundred years before Henry Cavendish [1731–1810] successfully demonstrated Newton's theory in a laboratory experiment. In practice one mass (M) is almost always a celestial body, most commonly the Earth, while the other (m) is typically a person or common everyday object that can be directly weighed on a scale. Mass is a property of each of the objects alone. Weight, on the other hand, although we often attribute it to the smaller object, is a measure of mutual attraction and depends on the masses of both objects and the distance between their centers of mass (r).

So where does the confusion come from? This is where a linguistic view can help. Many linguists, like other social scientists, envy the crisp clarity of the hard sciences and try their best to use the scientific method in their own work. Perhaps this is a situation where scientists could borrow back some of the precise descriptions and definitions that linguists have thus developed.

Discourse Communities

One fundamental principle in the field of semantics is that a word's meaning is determined by the way people in a certain discourse community use it (Jannedy, Poletto, and Weldon, 1994, 216). The concept of a *discourse community* (DC) reflects the complexity of modern human interaction and communication. There is a great deal of overlapping, and there are sub-communities within communities. Language groups form the largest discourse communities. In this paper we will restrict our discussion to the English language DC without worrying about the complexities of dialects, pidgins, and creoles. Yet we might note here that even language groups, which are relatively easy to identify, have a generous amount of (a) overlap in the form of bilingual or multilingual speakers and (b) interaction in the form of borrowing, especially vocabulary (see Blair, 1997 for a discussion of Japanese/English).

Let us now consider two discourse communities that will help us to distinguish the meanings of weight and mass in the "real" world and in the world of physics. We will say that people in the "real" world belong to the *general* **discourse community** (GDC) while scientists working in the field of physics belong to the *scientific* **discourse community** (SDC) *when* they are interacting as scientists with colleagues and students. Students new to any field can be viewed in part as language learners, and to that extent their teachers as language teachers. In this case, members of the GDC are trying to learn the specialized vocabulary of the SDC. Once we make a clear distinction between meanings for weight and mass in the two DCs, it is no longer a simple matter of confusing two words, but four (see table 1 below) — two in the GDC's English, which acts like a first "language" (L1) and two more of the same form (spelling and pronunciation) in the SDC's English, acting like a second "language" (L2) or target "language" (TL). The fact that the two "languages" have so much overlap only serves to obscure any differences across DCs that exist in the meanings of each word. Thus the learners might mistakenly transfer the GDC use of weight and mass to their interactions in the SDC. In Second Language Acquisition this is called negative transfer or interference.

General		Scientific	
GDC weight	⇒	⇒	SDC weight
GDC mass	⇒	⇒	SDC mass

Table 1　Language Transfer

Measures of Amount

Mass is a fundamental unit in physics, whereas weight plays a decidedly minor role. It appears like a shadow for the term mass, only to disappear once the harsh light of scientific inquiry has revealed that the two are not identical. As mentioned above, Hewitt (1999, 49) defines mass as the "quantity of matter in an object". How does one measure the quantity or amount of matter? This is an ancient art as old as civilization itself which depends on (a) what is being measured and (b) for what purpose. Let us look at some specific examples from GDC commerce and SDC studies of motion, using typical objects such as food, precious metals, balls, and pucks.

Perhaps the most primitive measure is to count the number of objects. Americans buy donuts and eggs by the dozen as long as they are of uniform size and quality. If the donuts or eggs are truly identical, then their number will be proportional to their SDC mass. To specify one is to specify the other. We can say number is functionally equivalent to mass with the unit of measurement being a single donut or egg. Likewise, in physics problems dealing with balls of a uniform shape (sphere), size, and material composition (steel), motion can be accurately analyzed simply by using the number of balls to represent their mass. A popular conversation piece which uses five identical balls suspended in a line to demonstrate the conservation of momentum is an example of such a simplification. Such a simple system of measurement is of limited use, since each unit (donut, egg, or ball) can only be applied to nearly identical objects.

In order to measure a wider range of objects with a single standard unit we could relax the conditions with respect to shape and try to measure volume. This works well for liquids and powders, as long as composition remains uniform. In Japan we buy liters of milk, while Americans buy quarts or gallons. With strict conditions on uniformity, size is proportional to and a valid measure of mass. Such a scale also allows us to measure mass along a continuum between the integers, since volume can be divided up and recombined to approximate any number of liters, quarts, or gallons. The motion of plastic pucks of uniform composition on an air plane can be analyzed using their volumes to represent mass. If their heights are uniform the square of the radius, since it would be proportional to volume and to mass, would be just as valid. Blocks of precious metal could be measured by size, but more complex shapes make volume quite difficult to measure. In addition the blocks might be hollow or filled inside with cheap metals so that an additional measure is necessary to verify internal composition.

This brings us to GDC weight as a measure of amount. Heaviness is a property of objects perceptually almost as salient as number and size. Although you cannot see it, you sure can feel it. Weight, furthermore, is much simpler to measure than size. One simple machine for measuring weight is a balance scale with two platforms on each side. You compare weights by putting a known weight on one side and the object whose weight is to be measured on the other. When both sides balance evenly, the weights are equal. A slightly more sophisticated machine, such as many doctors used to use in their offices, might incorporate a lever. The principle is the same. After taking account of distances from the balance point, you are comparing a known weight with an unknown weight. More common today than a balance scale is a compression scale such as the bathroom scales often found in people's homes. You step on the scale so that the force of gravity pushes you against the top of the scale, while the floor and Earth support the bottom. This compresses springs inside. The amount of compression has been calibrated over a range of weights. People do not need to worry about shape or size. As long as the object to be measured fits on top of the scale, they simply place it there and look at the readout. To be really accurate and avoid the distortion of buoyancy provided by the sea of air that surrounds us, measurements can be made in a vacuum. For centuries weight has been the best measure of amounts of relatively dense objects from precious metals to meat at the supermarket. The measure of heaviness is so special that it even has its own verb — to weigh. This has been and continues to be an ideal system for Earth-bound people, who if they admit it still function from day to day with a flat-Earth mentality.

In the 17th century came calculus and Newton's Laws of Motion. Physics tackled the mystery of orbiting planets and discovered gravity. A mechanism to explain gravity still alludes us. One popular theory suggest it's the work of gravitons. Some people jokingly say it's because the Earth sucks. Others don't care, they just think it is an attractive name for a condominium (Gravity Motoyama). Whatever gravity is, the planets' orbits seemed to be related to their heaviness. Since the planets could not be weighed as is done with common objects on Earth, this new kind of heaviness had to be measured by centrifugal forces or inertia, leading to the distinction of weight and mass. SDC weight is a measure of how heavy an object feels when the gravitational field of a second, usually a massive, object, like a planet, tries to accelerate it. SDC mass is a measure of how heavy an object feels when you try to accelerate it in the absence of, or horizontally to, the gravitational field. These measures of heaviness are exactly proportional when the gravitational field is held constant. The gravitational field, however, varies according to two factors: (a) the mass of the second object and (b) the distance away as measured from the center. Weight turned out to be more complicated in space than in the nearly uniform gravitational field on the surface of the Earth.

We have reviewed four measures of amount: (a) number, (b) size, (c) GDC weight, and (d) SDC mass. Each has proven useful and continues to be used for certain scientific and commercial applications. If the physical world were composed of steel balls or a single atomic particle rather than neutrons, protons, and electrons, mass could be assigned quantum numbers at a certain level of analysis. If all objects had uniform density, size would be an appropriate measure of amount. If the gravitational field were constant throughout the universe, weight and mass would be completely equivalent.

Semantic Complexity in the GDC

Let us assume that the physics textbook definitions above are the accepted meanings of weight and mass in the SDC. As *prescriptive* definitions (see Jannedy, Poletto, and Weldon, 1994, 216), they designate proper use of the given terms in the field of science. To avoid ambiguity, a single definition is usually agreed upon for each term. Similarly we will use definitions from Webster's New World Dictionary of the American Language (Guralnik, 1980) as a *description* of meanings in the GDC. Because the GDC has a much larger, more diverse population and very little linguistic control, our dictionary has not one, but seventeen definitions for weight and ten for mass. In the "real" world multiple definitions are the norm and there is a great deal of overlap in these definitions. The overlap makes it hard to distinguish exactly where one definition ends and another begins.

Weight
as a **noun** (definitions 1–12)
literal use (definitions 1–6)
  quantity or amount of heaviness (definitions 1–3)
  physical object (definitions 4–6)
figurative use (definitions 6–8)
  burden (definition 6)
  importance (definition 7)
  influence, power, or authority (definition 8)
specialized use (definitions 2 and 9–12)
  in physics (definition 2)
  for fabric (definition 9)
  in printing (definition 10)
  in sports (definition 11)
  in statistics (definition 12)
as a **verb** (five more definitions)

Since each of the verb definitions is associated with one or more of the nouns, we can probably eliminate them as majors source of semantic overlap and confusion in favor of the associated nouns. The specialized uses in definitions 9–12 occur in such restricted circumstances that they, too, are unlikely candidates for sources of confusion. It is hard to see how figurative uses of weight — such as the *weight* of responsibility or a matter of great *weight* could possibly be applied in the physical sciences. This leaves us with the first six *core* definitions of weight. Definitions 4–6, unlike the SDC definitions, refer to heavy objects or loads themselves, rather than the heavy quality of those objects and can thus be discarded. This leaves us with three remaining definitions.

1. a portion or quantity weighing a definite amount
2. heaviness as a quality of things;
   Physics — the force of gravity acting on a body, equal to the mass of the body multiplied by the acceleration of gravity
3. quantity or amount of heaviness; how much a thing weighs or should weigh

(Guralnik, 1980, 1612)

Let us examine these three GDC definitions more closely to see how they might differ from the SDC definition of weight discussed above. Definition 1 stipulates objects of a *definite* weight without reference to location or a second object. Yet SDC weight requires two objects (m and M) and depends on their distance apart (r). When I say my weight (m is me) is 80 kg to people in Japan or 174 pounds to people in America, it has to be assumed that I am talking about my terrestrial weight (M is the Earth) on the surface of the Earth (r is 6,378 km from the center). I do not specify an altitude, although weight decreases slightly at higher altitudes. Nor do I specify the latitude even though I realize that the oblateness of our planet causes about a 0.5% variation in weight: heavier at the poles than the equator which is 13.5 miles (21.7 km) further from the center of the Earth (Hamburg, 1993, 20). The human experience with lunar weight has been extremely brief and has involved very few people. While scientists tend to acknowledge the obvious and lawyers purposely build a great deal of redundancy into contracts and cross-examinations,the GDC usually tries to"be brief". Linguists refer to this as Grice's 3rd Maxim of Manner (Jannedy, Poletto, and Weldon, 1994, 238). It provides one possible explanation for why weight is treated as if it were an attribute of a single object. Everyone naturally assumes that any discussion of weight refers to ***terrestrial surface*** weight.

An alternate interpretation, however, is that GDC weight *actually is* independent of location. When someone says that they would weigh 29 pounds on the Moon, they are talking *figuratively* not literally. They are really talking about *apparent* weight. It would *seem as if* they weighed 29 pounds. The figurative meanings of weight in definitions 6–8, give such a metaphorical interpretation ample legitimacy. It is, of course, exactly this fuzzy kind of metaphorical use of key terms that the SDC seeks to avoid when fashioning their own precise prescriptive definitions.

Definition 2 also ignores any influence that location might have until adding the GDC definition of the SDC meaning after the "physics" heading, where the *force* of gravity and the *acceleration* of gravity are literally factored in. This inclusion could have profound implications for use since both force and acceleration, like velocity, are *vector* quantities. Forces accelerate objects in specific directions. This makes forces, including forces of gravity and thus weight, vector quantities. Direction depends on the location of the second object, while magnitude depends on both masses and the distance of separation. Take the Earth as an example. How much does it weigh? If it were floating all by itself in space we could say its weight was zero. No gravity, no weight. To have gravity and weight we need a second object. To maximize the force of gravity the second object (M) should have great mass or be very close (like the Moon). The Sun, which contains more than 99.8% of the mass of our solar system, is $3.33\ 10^5$ times as massive as Earth, where we usually weigh things, but is $23.46\ 10^3$ times as far from the center of the Earth as is the Earth's surface. So we can say the **solar** weight of the Earth is

$$\frac{597\text{kg}\ \ 10^{22}\text{kg}\ \times\ 3.33\ \ 10^{5}}{(23.46\ \ 10^{3})^{2}} = 361.53\ \ 10^{19}\text{kg}$$

This is the weight and the force that keeps the Earth in orbit around the Sun. The moon, with only 0.0123 as much mass as the Earth, is not nearly as massive as the Sun, but much closer to the Earth, only 60.27 times the Earth's radius. So the **lunar** weight of the Earth is

$$\frac{597\text{kg}\ \ 10^{22}\text{kg}\ \times\ 0.0123}{(60.27)^{2}} = 202.34\ \ 10^{17}\text{kg}$$

This is also the **terrestrial** weight of the Moon and the force that keeps the Moon in orbit around the Earth. This equality of weights follows from the fact that the force of gravity is a mutual attraction. Both bodies attract each other with the same force, which is proportional to the product of their masses. Their masses are different, but the product of the masses is the same (by the distributive property of multiplication). With this in mind, I might ask what is the weight of the Earth on the surface of this author. The answer is easy, the same as my weight on the surface of the Earth, about 80 kg.

Like the Earth we each have a solar weight and lunar weight as well as our terrestrial weight. Why are we not aware of them? Is it all right to ignore gravitational contributions to our weight of all the planets except the one we are on? Yes, since the distance between a planet and the Sun are so great in comparison to the radius of each, solar gravitation on the surface of closest planet is only about 1% of the Mercury's own surface gravity and drops off sharply at increased distances. Planets, which have much less mass than the sun exert proportionately less influence on each other.

SDC Weight of Moving Objects

So far we have considered only the weight of objects which are held stationary (a) on the surface of Earth or the Moon by the Earth or Moon's gravity or (b) in space by a balance of gravitational forces. The use of "acceleration" in the (GDC) definition of SDC weight, however, compels us to consider the weight of moving objects. Let us now consider the case of an orbiting object. If an object, like an artificial satellite, is in a stable orbit around the Earth at a high altitude, what is its SDC weight?

The Earth's gravity certainly exerts a force upon the object and that accelerates the object toward the center of the Earth, so it has some (SDC) weight. The force of gravity and that acceleration are less than they would be close to the surface of the Earth because the force of gravity decreases as the distance from the center of the Earth increases (radius of the Earth plus altitude). For simplicity's sake we are disregarding the much smaller gravitational forces of the Moon, the Sun, and other distant celestial bodies. There is no balance of gravitational forces here. Yet the object maintains a fixed altitude (a stable orbit) because the gravitation force, perpendicular to the direction of the object's motion around the Earth produces a change in direction that matches the curvature of Earth. The orbiting object is actually in a free fall situation-falling around and around the Earth but never hitting the surface. That is the geocentric perspective. From the satellite's perspective, the direction of the vectors of force would rotate around it canceling each other out with each complete orbit.

According to either view, as long as the altitude remains fixed, the *scalar* weight of the satellite is constant, less than it would be at the Earth's surface but greater than zero, while its *vector* weight continually rotates around it. Astronauts may be weightless in GDC discourse, but they are NOT weightless according to our SDC definition.

Semantic features can be used to analyze the varying degrees of this overlap in meaning and bring some order to an otherwise chaotic situation. Here is a list of some possible semantic features that might be useful in teasing through the various definitions of weight and SDC mass:

features \ definitions	SDC weight	GDC weight			SDC mass
		1	2	3	
the object itself	−	+	−	−	−
single-object attribute	−	−	+	+	+
two-object attribute	+	−	−	−	−
quantity	+	−	?	+	+
vector	+	−	−	−	−
location dependent	+	−	?	−	−
gravity dependent	+	−	+	?	−

Table 2 Semantic Features

Mental Images of the Act of Weighing

The semantic representations of words often seem to include mental images (Jannedy, S., R. Poletto, and T. Weldon, 1994, 217). A word may thus conjure up a typical or ideal image. The typical image of bird might be a robin, eagle, or hawk, rather than a penguin or ostrich. What images are associated with the word "weight"? Being a quality, rather than an object, the image would probably involve an image of (a) the *act of weighing* something or (b) *feeling weight* when picking something up.

GDC definition 3 above might, in fact, be interpreted as *defining* weight as the quantitative result of the *act* of weighing an object. We have already described the two most common methods for weighing objects on Earth: the balance scale and the compression scale. If their measurements are an integral part of the GDC definition, then we might ask ourselves whether those measurements are affected by location. What happens when we move a balance scale to a different location — a higher altitude or a different planet? Absolutely nothing. The SDC weight of everything changes in equal proportion, so the conditions to maintain balance — the "known" weights and their position on the lever — remain the same. The GDC weight, according to definition 3 using this kind of weighing machine, would give the same numerical value on the surface of any planet. The readings on a compression scale, however, would depend on location such that values on the Moon would be one sixth of what the machine registers on the Earth.

The compression scale measure of weight is closely related to our second mental image of weight, the feeling of weight due to the downward pressure of our own body weight or the muscle tension necessary to hold a heavy object. These feelings and the readings of a compression scale are affected not only by gravity, but also by accelerations. Hewitt (1999, 186–187) acknowledges this "more practical" definition — "the force [an object exerts] against a supporting floor" rather than "the force of gravity that acts on [it]" — nine chapters after introducing weight and mass and illustrates it with an elevator ride. We feel a greater downward pressure when the elevator starts to go up, less when it starts to go down, and none (until we hit bottom) if the cable snaps sending us into a free fall. Similar accelerations can and do occur in *horizontal* directions whenever cars and trains accelerate or slow down, but weight seems to be considered a *vertical* phenomena only, with direction determined by a single dominant, celestial body usually at or close to its surface. Elevator rides and horizontal accelerations are temporary and artificial. There is, however, a slight, constant, natural acceleration due to the centrifugal force of the Earth's rotation (Hamburg, 1993, 20). It varies with latitude decreasing the weight of things located on the equator the most and less so towards the poles. And how should we treat buoyancy? When we step into some water does our weight decrease as we wade deeper becoming zero or even negative when we begin to float? Our downward pressure *does* decrease and may even become upward pressure. What about the slight buoyancy caused by the sea of air that continually surrounds and sustains us? Hewitt does not make clear whether his "more practical" definition is valid within the SDC or simply an example of GDC practicality.

We could say that the balance scale measures SDC mass, while the compression scale measures SDC weight. Yet both are used to "weigh" objects and find their GDC weight. There is no special verb associated with mass, as opposed to weight, in either the SDC or the GDC. In fact, the GDC usually uses the noun "mass" to describe an unquantifiable but large amount of matter itself rather than a specific quantity of heaviness. According to Webster's New World Dictionary of the American Language (Guralnik, 1980, 872):

Mass
as a **noun** (definitions 1–7)
literal use (definitions 1–4)

1. a quantity of matter forming a body of indefinite shape and size
2. a large quantity or number
3. bulk; size; magnitude
4. the main or larger part

specialized use (definitions 5-7)

5. Painting — a large area or form of one color
6. Pharmacy — the paste or plastic combination of drugs from which pills are made
7. Physics — the quantity of matter in a body as measured in its relation to inertia; mass is determined for a given body by dividing the weight of the body by the acceleration due to gravity

Units of Weight and Mass

In physics the focus is on SDC mass and the motion of planets, cannon balls, and atomic particles. Whereas in the GDC focus is on amounts — size, volume, and GDC weight — of various economic commodities measured on the surface of a hard and apparently flat surface with a nearly uniform field of gravity. SDC mass for planets and atomic particles cannot be measured directly, it must be calculated from the motions that scientists observe. For cannon balls and other moderately sized objects, scientists *could* measure SDC mass on the basis of centrifugal forces by swinging them in horizontal circles or momentum by crashing them into other objects of known mass, but it is much easier and more common simply to weigh them on a scale. For the everyday objects around us SDC mass and GDC weight are measured in the same way.

In Japan I step on a scale that measures my heaviness as 80 kilogams, in America a scale that measures it as 176 pounds. The scales are the same and could just as easily be calibrated in Newtons or slugs. All four values are proportional. It seems arbitrary to label two values, Newtons and pounds, as weight, the values in kilograms and slugs as mass, and treat them as two completely different entities (see table 3 below). As long as all four measures remain proportional they can be considered measures of the same phenomenon — heaviness. The first, most salient meaning in the GDC for "heavy" (Guralnik 1980, 647) is "hard to *lift* or *move* because of great weight [italics added]" (Guralnik, 1980, 647). It is very interesting that both lift and move are used in this definition. The term "lift" seems to emphasize the role of gravity, while "move" (horizontally or in a gravity free environment) would seem to include the role of inertia. The constant of proportionality can be incorporated into any one of these units during the calibration of a measuring device.

country / word	United States	Most Countries
GDC force	pound (of pressure)	Newton
SDC force and weight	pound	Newton
GDC weight	pound	kilogram
SDC mass	slug	kilogram

Table 3　Units of Force, Weight, and Mass

Conclusions and a Linguistic Solution

The fundamental difference between SDC weight and mass is to be found in the mathematical expressions for each after they have been stripped of units and constant factors.

Binary Component	Object 1	Object 2
SDC mass	m	M
SDC weight	$m\ (M/r^2)$	$M\ (m/r^2)$
GDC weight	$m\ (597\ /\ 6{,}378^2)$	n.a.

Table 4　Formulas of Weight and Mass for a Binary Component

Mass has only one variable. It is a simple, single-object attribute. Weight requires at least two objects and three independent variables to characterize a binary component. More complex systems can be analyzed in terms of force vectors with each vector representing a component. Thus SDC weight should be considered a joint attribute of an independent binary entity. Traditionally a binary component consists of a relatively small object and a celestial body. For several reasons binary components can be often be treated in isolation: (a) gravitation is an extremely weak force, (b) the mass of our solar system and universe are concentrated in oblong, almost spherical bundles called stars and planets, and (c) these celestial bodies are separated by large empty spaces.

We can take advantage of this situation by treating each as a separate entity and giving them names. My total weight is really a composite of these components: my terrestrial weight, my lunar weight, et cetera. What happens to my weight if I travel to the Moon? The lunar component increases as the terrestrial component decreases. It is the lunar surface weight that is one-sixth of the terrestrial surface weight. This terminology makes it clear that we are comparing two very different entities. What about my solar weight? It is there but it escapes notice for two reasons: (1) it is very small, only 0.0006 of the terrestrial surface weight and (2) we, the Earth, and the Moon are all orbiting the Sun together. Since our masses are exactly proportional to our respective forces of gravitation, we all undergo the exact same accelerations and maintain the same velocities.

General	Scientific	Proposed
	SDC weight	solor weight terrestrial weight lunar weight
GDC weight	SDC mass	terrestrial surface weight
GDC mass		

Table 5　Relationship of Terms

When objects are falling or floating they do not feel their weight. You only feel your weight when you make contact with a surface that presses its weight against yours. The contribution of each object's mass is completely symmetric and indistinguishable from the other's. The weight of the Earth on my surface is the same as my weight on the surface of the Earth. It is when surfaces are in contact that we can feel the pressure their weight exerts and by slipping a scale between them measure that weight directly.

The GDC concept of weight is a consequence of a flat-Earth mentality, which has worked quite well for centuries and continues to do so, because of the nearly uniform gravitational field at the surface of the Earth. There is some deviation from complete uniformity due to the oblateness of the Earth, but it is slight. There are also some extraneous forces that may distort the measurement and the feeling of weight. Because they are temporary, horizontal, or very slight they pose almost no threat to our flat-Earth state of mind, in which GDC weight and mass are indistinguishable. GDC weight and mass are the same as SDC terrestrial surface weight which can be thought of as the standard for SDC mass.

It is only when we leave the surface of the Earth that the distinction between SDC weight and SDC mass becomes important. A spaceship Earth mentality brings with it a new image of weight. Not a single object resting on top of scale, but two objects, one very large and one very small, side by side with a compression scale between them measuring the pressure of their mutual attraction, otherwise known as weight.

Acknowledgments

Sincere thanks to three friends from my days at California Institute of Technology — Daniel Reichel ('73, systems analyst), Rik Smoody (Ex '74, computer software), and David Brin ('73, science fiction author) — for valuable critical comments on earlier drafts and encouragement. Not all of the advice received was necessarily heeded, however, and I retain full responsibility for the final product.

My love of mathematics was set in motion at Gunston Junior High School by a devoted teacher named Don Oliver Buttermore and accelerated by the force of an inspiring academic environment provided by the Class of 1966. Inertia has kept me going since then. This paper is gratefully dedicated to them and to my mother Rita Connelly Blair (MIT, Ex '40) and my father Robert Blair (1916–1978), who supported me in so many ways as I cruised through Culver Military Academy and the many detours my life took after I entered Caltech.

Points of Contact

Any comments on this article will be welcomed and should be mailed to the author at Aichi Gakuin University, Junior College Division, 1–100 Kusumoto-cho, Chikusa-ku, Nagoya, Japan 456–0037 or e-mailed to jeffreyb@dpc.aichi-gakuin.ac.jp. Other papers and works in progress may be

accessed at http://www.aichi-gakuin.ac.jp/~jeffreyb/research.

References

Blair, J. (1997). The role of English and other foreign languages in Japanese society. *The Faculty Journal of Aichi Gakuin Junior College*, 5, pp. 74–86. Reprinted in *The Internet TESL Journal*, Vol. III, No. 7, July 1997 at http://www.aitech.ac.jp/~iteslj/Articles/Blair-EngJpn.html.

Hamburg, M. (1993). *Astronomy Made Simple*. New York: Doubleday.

Feynman, R., R. Leighton, and M. Sands (1963). *The Feynman Lectures on Physics*, Vol. 1. Reading, MA: Addison-Wesley Publishing Co.

Guralnik, D. (Ed., 1980). *Webster's New World Dictionary of the American Language*, Second College Edition. New York: Prentice-Hall.

Hewitt, P. (1999). *Conceptual Physics*, 3rd edition. Menlo Park, CA : Scott Foresman-Addison Wesley.

Jannedy, S., R. Poletto, and T. Weldon (Eds., 1994). *Language Files: Materials for an Introduction to Language & Linguistics*, 6th edition. Columbus, OH: Ohio State University Press.

Larsen-Freeman, D. and M. Long (1991). *An Introduction to Second Language Acquisition Research*. London: Longman.

Oxford, R. and D. Crookall (1990). Vocabulary learning: A critical analysis of techniques. *TESL Canada Journal/Revue TESL du Canada*, 7 (3), p. 15.

Stockwell, R., J. Bowen, and J. Martin (1965). *The Grammatical Structures of English and Spanish*. Chicago: University of Chicago Press.