A Taxonomy of Misconceptions

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0. Kinematics
- K1. position-velocity undiscriminated
- K2. velocity-acceleration undiscriminated
- K3. nonvectorial velocity composition

1. Impetus
- I1. impetus supplied by "hit"
- I2. loss/recovery of original impetus
- I3. impetus dissipation
- I4. gradual/delayed impetus build-up
- I5. circular impetus

2. Active Force
- AF1. only active agents exert forces
- AF2. motion implies active force
- AF3. no motion implies no force
- AF4. velocity proportional to applied force
- AF5. acceleration implies increasing force
- AF6. force causes acceleration to terminal velocity
- AF7. active force wears out

3. Action/Reaction Pairs
- AR1. greater mass implies greater force
- AR2. most active agent produces greatest force

4. Concatenation of Influences
- CI1. largest force determines motion
- CI2. force compromise determines motion
- CI3. last force to act determines motion

5. Other Influences on Motion
- CF. Centrifugal force
- OB. Obstacles exert no force

Resistance
- R1. mass makes things stop
- R2. motion when force overcomes resistance
- R3. resistance opposes force/impetus

Gravity
- G1. air pressure-assisted gravity
- G2. gravity intrinsic to mass
- G3. heavier things fall faster
- G4. gravity increases as objects fall
- G5. gravity acts after impetus wears down

0. Kinematics

In kinematics it is really not appropriate to speak of commonsense misconceptions. Rather, the typical commonsense concept of motion is vague and undifferentiated. Accordingly, as indicated in the Kinematics category, the FCI probes for the ability to distinguish between position, velocity and acceleration, as well as to recognize the vectorial nature of velocity and acceleration. The most rudimentary concept of acceleration is "to know one when you see one."

1 Impetus

Commonsense beliefs tend to be metaphorical and vague with situation-dependent meanings. This is reflected in the use of language. Thus, terms like “force”, “energy” and “power” are often used interchangeably, as are the terms “velocity” and “acceleration.”Even so, most commonsense thinkers distinguish two kinds of force, which we will refere to as *impetus* and *active force*. The term “impetus” dates back to pre-Galilean times before the concept was discredited scientifically. Of course, students never use the word “impetus”’ they might use any of a number of terms, but “force” is perhaps the most common. *Impetus* is conceived to be an inanimate “motive power” or “intrinsic force” that *keeps things moving.* This, of course, contradicts Newton’s First Law. Evidence that a student believes in some kind of impetus is therefore evidence that the First Law is not understood.

For an object to move it must be *supplied* with impetus, as expressed by the commonsense concept I1 in the table. As expressed by concepts I2, I3, and I4, impetus can be gained or lost in a variety of ways that vary from student to student. Note the underlying “container metaphor” in the impetus concept: Every object is (like) a container that can store a supply of impetus, like a car stores gas, a kind of “go power” to keep it moving. A few students believe in circular impetus (commonsense concept I5) that tends to move objects in circles; which holds that objects tend to do what they have been “trained” to do in the past.

2. Active Force

The commonsense concept of active force is closer than impetus to the Newtonian force concept except, as expressed by concept AF1 in the table, it is attributed only to certain “active agents” (usually living things), and it acts only by direct contact. Active agents are *causal agents* – they have the power to *cause* motion – to create impetus and transfer it to other objects, as when a boy throws a ball. Active force is the commonsense concept that corresponds most closely to Newton’s Second Law. The commonsense notion closest to a “causal law” is expressed by the syllogism:

Every effect has a cause.

Motion is an effect.

Therefore, motion has a cause.

This leads to the commonsense concept AF2 (motion implies active force).

The vague commonsense analog of the Second law is that active force produces motion. When velocity and acceleration are not discriminated as descriptors of motion, it is to be expected that the concept “velocity is proportional to force” (commonsense concept AF4) is not distinguished from “acceleration is proportional to force.” Active agents have their limits; a limited capacity to produce motion and a tendency to wear out, as expressed by concepts AF6 and AF7. Note the metaphor of an “acting person” for an active force.

3. Action/Reaction Pairs

Students often interpret the term “interaction” by a “conflict metaphor.” They see an interaction as a “struggle between opposing forces.” It follows from the metaphor that

"victory belongs to the stronger." Hence, students find Newton's Third Law unreasonable, and they prefer some version of the *dominance principle*: In a conflict, the "more forceful" exerts the greater force. Here "more forceful" can mean "bigger," "greater mass," or "more active," as in commonsense concepts AR1 (greater mass impli es greater force) and AR2 (most active agent produces greatest force).

Because of its strong metaphorical base, the dominance principle (though it is seldom clearly articulated) is so natural to students that it is one of the last misconceptions to be overcome in the transition to Newtonian thinking. Indeed, it is still to be found in some physics graduate students.

4. Concatenation of Influences

Common sense offers a number of alternatives, as shown in category 4 of the table, to the Newtonian force superposition principle. Students often apply the dominance principle to the composition of two forces acting on the same object, with one force winning out over the other. Indeed, they often confuse action/reaction pairs with the superposition of oppositely directed forces on a single object. This is another example of poorly differentiated concepts so typical of commonsense thinking.

5. Other Influences on Motion

Unlike the Newtonian world, the world of common sense does not have a unitary concept of force. Besides active forces, there are other influences on motion, as listed in category 5 of the table. Actually, the FCI does not contain any items designed specifically to probe for the centrifugal force misconception listed in the table. That misconception is only suggested by the form that the listed items take in the questions. Verification would require an interview or explanation from the students. We have encountered high-school physics teachers who think that centrifugal force is a distinct *kind* of force. Such is the power of a name!

In the world of common sense, *obstacles* like chairs and walls do not exert forces, "they just get in the way." Mass is regarded as a kind of resistance, because it "resists" the efforts of an active agent. Motion occurs only when the active force "overcomes" the resistance (note the metaphor), and it ceases when the force becomes "too weak."

In the world of common sense, "gravity" is not necessarily the same as "gravitational force." When they are the same, the commonsense concept G3 (heavier objects fall faster) can be regarded as a special case of AF5 (acceleration implies increasing force.) Concept G3 may appear to be true, but the underlying misconception is a matter of scale, to which common sense is often oblivious. It is believed that gravity varies significantly over a few meters, whereas the variation is actually about one part in 10^{13}.