# A Taxonomy of Common Sense Concepts About Motion

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Section V. To organize our knowledge about common sense (CS) concepts and provide a guide for applying it to instruction, in this section we develop a brief annotated taxonomy of the most significant CS concepts. It would be impractical to categorize the many variations of each concept found among students, so we have attempted to give formulations of the concepts which express the most common beliefs.

To develop a taxonomy, we need classification principles. Fortunately, Newtonian mechanics provides us with a ready-made classification scheme, and we can classify CS concepts about motion as alternatives to specific Newtonian concepts. Accordingly, we recognize two general categories: *principle of motion*, corresponding to Newton's Laws of Motion, and *influences on motion,* corresponding to specific laws of force in Newtonian mechanics.

### A. Principles of motion

(1) *Description of motion:*

CS kinematical concepts commonly have the following characteristics:

- (a) The concepts of "time interval" and "instant of time' are not differentiated. An "instant" is regarded as a very short time interval.
- (b) Velocity is *defined* as distance divided by time. Thus average velocity is not differentiated from instantaneous velocity.
- (c) Concepts of distance, velocity, and acceleration are not well differentiated.

(2) *In the absence of forces, every object remains at rest (with respect to the earth).*

In a common sense system, this principle plays a role analogous to Newton's First Law. The tacit adoption of the earth as a preferred reference frame is especially significant, as it is undoubtedly based on direct perceptual experience. One of the marvels of the human perceptual system is the fact that from diverse sensory input it creates a representation of an environment at rest while the observing subject moves, rather than one in which the observer is always at rest while the environment moves. Of course, the testimony of the senses in not to be denied; rather, Newtonian theory tells us how it should be reinterpreted to be consistent with a wider range of experience. This example suggests that to deal most effectively with particular CS beliefs, instructional design should depend on how those beliefs are grounded in perception, but that is a matter for future research.

(3) *The causal principle of motion: Every motion has a cause.*

This is a CS analog of Newton's second law.

- (a) *Motion is started* by
  - (i) *a force* applied to the object by an external agent;
  - (ii) *gravity*, an intrinsic tendency to fall down.
- (b) *Motion is sustained* by
  - (i) continuous action of an applied force or gravity.
  - (ii) an *internal force (Impetus)* in the object.
- (c) *Motion may be opposed* by
  - (i) intrinsic resistance (weight or mass) of the object,
  - (ii) resistance of a medium surrounding the object,
  - (iii) obstacles that "get in the way."

The action of a resistive medium or an obstacle is not an active force, because it does not start or sustain motion. It may, however, be called a *reactive force*, to help students develop a general force concept.

(4) Newton's third law is inconsistent with common sense intuitions. Maloney[1] has studied classification rules generated by students to deal with situations where the third law applied. He found that most students characterize the reciprocal interaction between two objects by some sort of *dominance principle*:

(a) The greater mass exerts the greater force, or more frequently,

(b) the object which causes motion of the other exerts the greater force, because it overcomes the other's opposition.

(5) The Newtonian superposition principle (Vector addition of forces) has two CS analogs:

(a) *Dominance: Motion is determined by the larger of two competing forces.* This principle has a natural origin in the experience that, to move a heavy object, one needs to push harder and harder until the push "overcomes" the resistance, and less effort is needed to maintain motion. A student needs to reinterpret this experience to accept Newtonian theory. Textbooks statements such as "resistance can be neglected," might be interpreted by students as confirmation of the dominance principle.

(b) *Compromise: Motion is determined by a compromise among competing forces.* Of course, the superposition principle can be regarded as a kind of compromise, but student ideas of compromise are likely to be vague or involve an impetus. Sometimes dominance and compromise principles are used together, as we saw in connection with Fig. 4.

## B. Influences on motion

(1) An *applied force* is a push or pull exerted by an agent in direct *contact* with the object. For some, only the living things are recognized as agents of force. The effect of an applied force is commonly characterized by the following *causal principles*:

(a) *Inertial resistance*: A force cannot move an object unless it is greater than the object's weight. Weight is not distinguished from mass.

(b) A *constant force produces a constant velocity*, sometimes expressed as $F = mv$.

(c) *Acceleration is due to increasing force.*

(d) *A constant force has a limited effect depending on its magnitude*. The limitation may be one of two kinds:

(i) The force wears out, due to its consumption by the motion or its dissipation by resistive agents. Furthermore, its effect may not be instantaneous, in the sense that the effect may not start until sometime after the force is applied.

(ii) The force $F$ accelerates the object until it reaches a critical speed proportional to $F$, which the object maintains afterwards whether or not the force is still applied.

(e) A *long-range force* must be transmitted by a medium such as a rope connecting object and agent. Therefore, long-range forces cannot act on an object in a vacuum.

(2) An *Internal force* (or impetus) maintains motion of an object independent of external agents. As Clement[2] observed, by this principle students frequently infer the existence of a force in the direction of the object's motion.

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[1] D. P. Maloney, "Rule-governed approaches to physics. Newton's Third Law," Phys. Ed. **19**, 37 (1984).

[2] J. Clement, "Students' preconceptions in introductory mechanics," Am. J. Phys. **50**, 66 (1982).

(a) An impetus can be imparted by an applied force and transmitted from one object to another.
(b) The impetus of an object is proportional to its mass and velocity, as expressed by the equation $F = mv$.
(c) An impetus may wear out or build up in the same way as the effect of an applied force.

(3) Resistance opposes an applied force or consumes the impetus of a moving object. The following kinds of resistance are not always distinguished:
(a) *Inertia* (weight or mass) is an intrinsic resistance of an object to motion.
(b) Friction due to contact with a solid surface.
(c) Fluid resistance depends on the density of the fluid as well as the size, shape, and weight of the object.

(4) *Obstacles* may redirect or stop motion, but they cannot be agents of an applied force. Minstrell[3] has analyzed student concepts of reactive forces.

(5) *Gravity* is a tendency of objects to fall down. In this conception, gravity is not necessarily a force. Nevertheless, the causal principles for applied forces which we quoted above may be attributed to gravity as well. As we saw in our discussion of Aristotelian physics, an important consequence of those principles is the belief that *heavier objects fall faster*. This belief is so common that it deserves to be examined carefully in physics classes.

In the preceding sections we noted a number of other beliefs about gravity, and more are noted by Gunstone and White.[4] But more important than particular beliefs about gravity may be the uncertainty of students about what gravity "really is." So the best teaching strategy may be the direct one that aims at *convincing* students that gravity is a force, in particular a long-range force. The idea of a long-range force is difficult for students to understand and accept, as it was for many great intellects in history. Historically, Gilbert's study of magnets did the most to convince people of the reality of long-range forces. Physics instructors may draw a pedagogical lesson from this.


2. D. P. Maloney, "Rule-governed approaches to physics. Newton's Third Law," *Phys. Ed.* **19**, 37 (1984).
3. J. Clement, "Students' preconceptions in introductory mechanics," *Am.J. Phys.* **50**, 66 (1982).
4. J. Minstrell, "Explaining the 'at rest' condition of an object," *The Phys.Teach.* **20**, 10 (1982).
5. R. F. Gunstone and R. White, "Understanding gravity," *Sci. Ed.* **65**, 291 (1981).


[3] J. Minstrell, "Explaining the 'at rest' condition of an object," Phys. Teach. **20**, 10 (1982).

[4] R. Gunstone and R. White, "Understanding gravity," Sci. Ed. **65**, 291 (1981).