

Difficulties of dynamics and some uses for microcomputers

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1. The dynamics everyone knows

One reason dynamics is difficult to learn is that everyone already knows a lot of dynamics from everyday experience, and that everyday knowledge conflicts with what Physics has to teach. This difficulty is often expressed by saying that students are Aristotelian in their thinking. I doubt if this is in fact the right formulation of the problem: rather, I think that a much closer examination of the dynamics everyone knows is needed, and that if this is done we get much closer to a grasp of why the intellectual organ transplant of Newtonian dynamics is so readily rejected.

The following is a first attempt to characterise this everyday knowledge, rather in the form of 'laws of everyday physics'. They derive in great measure from Hayes (1979).

The first law we may call the law of support. It says that everything needs to be supported, and if not supported, it falls. Only one thing does not need support: the ground. Thus the reason something falls is that it was let go, fell off, etc., in short that its support has vanished.

There are several kinds of support: from above ('held', 'hanging'); from below ('resting on'); from the side ('attached to'). Humans also support things, for example by carrying them. Water and air can sometimes support things ('floating').

Giving support needs either strength or effort. A support which is not strong enough may break, and let what it supports fall. But if the strength is enough, support can be given without using effort. So far as people supporting things is concerned, effort is generally needed. One gets tired holding a valise. However, some things can support themselves using effort: examples are swimming, or aeroplanes flying through the air, or birds. If the sea is not quite strong enough to support your body you can use up effort swimming to make up the difference.

The second law is the law of falling. The cause of falling. The cause of falling is in the law of support: a thing goes on falling because it has not yet found any support. No force is needed: falling is a natural motion not requiring a continuous cause, but only a continuous absence of a reason to stop. Once having started to fall, things fall at a constant speed, which is faster the further they have to go and the heavier they are. Falling uses up no effort, but may need effort or strength to stop. But starting to fall needs effort, which is supplied by gravity.

One immediate prediction is that gravity gets stronger higher up, since gravity has to supply the extra effort to make the object fall faster. It turns out that this is in fact one of the unexpected things everyone knows, if one troubles to ask children about it. It is also well worth dropping a coin and watching carefully: I have yet to find anyone, including myself and many physicists, who are able to see anything except a constant speed of fall!

The third law is the law of motion. This law distinguishes two essentially different kinds of motion:

- (a) displacement 'put', 'push', 'go to'
- (b) trajectory 'fly', 'throw', 'keep going'

Displacement motion is the kind associated with my asking you to pass the wine: you just move the bottle from where it is to where you want it to be. The effort needed is in proportion to the distance the object is moved, and to its weight.

Trajectory motion is the kind associated with throwing and catching a ball: the initial effort sets the ball going and that effort keeps it going, until it is used up or until it is overcome by gravity. This motion includes rolling and coasting along, for example a ball rolling along the ground after being kicked. The effort needed for trajectory motion is in proportion to speed, not to distance, and also in proportion to weight.

All motion required initial effort, but in displacement motion effort is needed for the whole displacement, while in trajectory motion the effort is given to the moving object, which stores the effort. Many motions require continual effort, for example a car or athlete to keep going and an aeroplane both to keep going and to keep up. Things like cars have an internal source of effort - the engine - which they use to keep moving.

It would be wrong to think of this as just a collection of bits of practical knowhow. It is a rather self-consistent explanatory system, which does a good job of telling us how and why things happen. It is not, of course, a formalised and logical scheme but it has enough of the properties of such schemes for the exposition in terms of 'laws' not to be absurd.

2. Why intelligent mammals living on the earth ought to believe the laws of everyday dynamics

It is only a decade or two since computers could first do Newtonian dynamics fast enough to know what to do in real time: to calculate a motion before it happened, so as to be able to steer rockets to the Moon. Physics, in fact, might be regarded as a subject where action is put off in favour of getting the answer right - we wait a few hundred years if necessary to really understand. But living is a different matter, and human and other animals have urgent need to be able to predict things fast enough to anticipate what will happen, so as to take corrective action or so as to plan ahead. In dynamics, much is not done by thinking (one ducks as the ball comes near, and only later feels afraid), but some is. We do need rules to tell us what will happen and how to manage matters.

Everyday dynamics is a part of those rules. It is the system of 'calculation' we use when we pass things, push or throw things, run, walk, jump and so on. Why then, we may ask, should we have developed such a scheme? The answer is that it is a very good scheme for brainy mammals living in a strong gravitational field with rather high surface friction and rather low air resistance.

Gravity, to use words in their physical meaning now, is everpresent. We never need to take action which allows that there might be no gravity, so we have no need for the idea at all. That which is never absent is invisible! Hence the main features of the laws of support and of fall.

There are enough strongly covalently bonded materials around for support to be a static notion, with no thought needed for the strain energy, or the relatively tiny strain, of solid objects which support others (A fuller story of everyday dynamics should accommodate bending however).

It would seem to be the marked difference between the magnitudes of solid-solid surface friction and v^2 -dependent air resistance which makes it rather reasonable for us to have two kinds of motion in our everyday theory. Certainly trajectory motion belongs mainly in the air though we assimilate rolling things to it also. However, there is something else, not to do with the physics of the world, which matters too.

One good reason for our having a special displacement category of motion is that we are (amongst other things) goal-seeking feedback systems. If I try to pass you the wine, I pay attention to where the bottle is and to how fast it is going as I pass it, and my brain uses the position and velocity feedback information to control the action. Thus my felt experience of passing the wine is precisely of passing the wine - putting it where I want - and not a Newtonian experience of accelerating a mass, letting it move at constant velocity, and then decelerating.

it again. Not even a factory robot which passes spare parts using such feedback loops will have in its 'intelligence' ideas about acceleration: it too will just know about where the object is and where it must be put, notwithstanding the fact that its motors must obey Newton.

3. Why is dynamics difficult ?

Conventionally, one introduces dynamics (and statics) through constant continuously acting forces. Impulsive forces, or kicks, are treated as an integral over a short time interval, which makes them look difficult. Yet surely a short sharp kick, or throw, is the simplest case of applying a force, from the point of view of everyday dynamics. Kicks are part of our commonsense world, because (from a Newtonian point of view) we are massive enough and have large enough friction with the ground to be able to push a number of objects around without ourselves seeming to move. The commonsense continuous forces, like the support of a crane for a block of concrete, are static in character and easily 'vanish' from our minds (we do not think of houses holding up their roofs all the time).

Kicks have another advantage: continuous forces produce accelerations, that is, rates of change of a rate of change. It is hard enough to grasp the idea of a velocity at an instant, and harder still to grasp its rate of change. Kicks just produce a change of velocity.

We can perhaps sum up why dynamics is difficult in three statements:

1. The first law is unbelievable

Children live in a world with friction, and cases where there is little of it are very exceptional. Indeed 'friction' all too easily becomes the name of the excuse given in school for school dynamics not being really true!

2. The second law is incomprehensible

A rate of change (dx/dt) is hard enough, and a rate of change of a rate of change (d^2x/dt^2) worse. The deep truth of the Newtonian system, that forces act by changing velocities, is overlaid by technical difficulties.

3. The third law is merely a religious incantation

Children learn to speak of every force having an equal and opposite one, but the idea makes little sense. It is especially senseless in 'explaining' what commonsense calls support, making a book just resting on the table into a big problem, and often leading to teachers themselves telling lies such as that the weight of the book has its reaction in the upward push of the table.

4. Kick dynamics and some computer games

'Kick dynamics' is just the dynamics of short sharp blows given to an object

by one which is much more massive. It is more or less the dynamics used in football and other games.

One way to help teach 'kick dynamics' is to use a microcomputer. The ideas described here derive from work by Judah Schwartz and by Andy diSessa, both of MIT. An object can be moved around the screen by kicks delivered by pressing keys. Eight possible directions as shown in figure 1 is good, but just the four 'up', 'down', 'right' and 'left' will do. A simple game to begin with is one where the player shoots for a target region, as in figure 2. If the object is moving across the screen to start with, a downward kick sends it off at an angle, not downwards. The single most important lesson, that objects do not move in the direction in which they are kicked, begins to emerge.

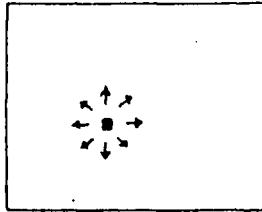
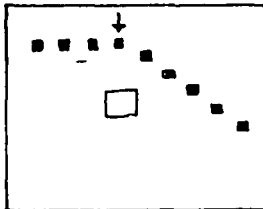
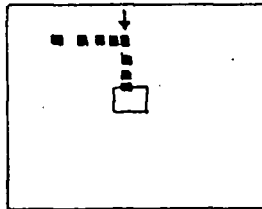


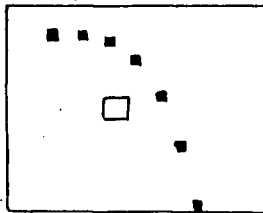
Fig.1 Eight possible kick directions



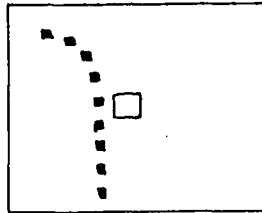
(a)



(b)



(c)



(d)

Fig.2

- (a) a single kick to a moving object
- (b) as (a) but with friction on
- (c) gravity on, but no friction
- (d) gravity and friction both on

It is easy in such a program to turn friction and gravity on and off. If friction is on, it now is possible to kick where you want to go, as in figure 2(b). The trick is to wait until the object stops. Notice also that with friction on, we get something like 'displacement motion' with more kicks sending the object further. With gravity on, the object falls; with both gravity and friction on we see that the Greek idea of the path of a projectile is not so absurd (figures 2(c) and (d)).

An artistic variation of the game is a painting or drawing program, in which the object may be made to leave coloured trails behind it. To write your name with a Newtonian object is far from trivial!

Maze games (figure 3) are particularly useful for teaching about the vector nature of kicks. To turn a corner, one soon learns to kick into the corner, that is, partly backwards and partly along where one wants to go. One also learns not to go too fast, and thus how to slow down by back-kicking. The same lessons can emerge from drawing curves in a painting program.

A further game of some interest is a chasing game, in which the computer itself commands an attacker (or defender) who chases (or is chased by) the object controlled by the student at the keyboard. One useful way to program the movement of the computer's object is to give the machine just the same (four or eight) kicks as the user, and get it to calculate where each kick would land it, and then to apply that kick which lands it closest (or furthest) from the opponent. In such a programme, one soon learns to tempt the machine into rushing towards you and then to sidestep (for which one must be going slowly), using the fact that when it is going fast it cannot change direction easily.

Another variation of interest is to make the machine simply kick towards the opponent. In this case the result, clear to those who have studied central forces but surprising to children, is that if it tries to chase you it generally orbits foolishly around you. But, if friction is turned on, this 'kick towards the goal' strategy works much better.

The idea of how the machine makes gravity can be got by seeing what happens if one kicks downwards at every move, as in figure 4. The result is a parabola (with no friction). The object coasts sideways at a constant speed, but goes faster and faster downwards.

Educationally, it is important to be able to control just how the programs work. It is very attractive to let them run continuously, when the objects move on the screen as if on ice. But in this mode, there is a danger that children just press keys to produce visual effects, indeed that they may learn reactions of the fingers to do what they want on the screen, without having to think. Thus such programs

Programs so far written, then, allow users to switch gravity and friction off and on, and to switch between continuous and pausing modes, as well as to switch tracing of motions on or off.

The law of kick dynamics are simply expressed (see figure 5). In the computer language BASIC they can be written:

$$V = V + K$$

$$S = S + V^*dT$$

in one dimension, or in two:

$$VX = VX + KX$$

$$VY = VY + KY$$

$$SX = SX + VX^*dT$$

$$SY = SY + VY^*dT$$

In brief, a kick K changes the velocity by a fixed amount, and the displacement then results from the new velocity. In two dimensions, the angle of a kick decides X- and Y-components KX and KY .

5. Collision dynamics

To move on to something more general than kick dynamics, it is not unreasonable to go next to the dynamics of collisions.

The first basic idea is that any change in motion can be traced to a cause which is an object (not an abstract force). A ball bounces back off a wall, or a truck hits another and sets it moving. We can think of simplifying situations by systematically removing interactions: ice or wheels help reduce the effect of the floor on a moving cart. Flat tracks prevent the pull of the Earth making things fall.

Now we can study interactions between pairs of objects (figure 6). We find that, whatever the collision, if the objects are identical their changes in velocity are equal and opposite. If one is twice as big as the other its change in velocity is half as big. In general, we introduce a quantity m such that

$$m_A \Delta V_A = m_B \Delta V_B$$

Experiment determines how many times bigger one mass is than other, but people decide on some arbitrary unit.

Thus in this approach we introduce momentum conservation before force. We do so because (a) it is easier and (b) it is more fundamental.

To get to forces, we 'look inside' collisions. Figure 7 suggests a 'slow' collision with a thin elastic thread joining two trucks. We find that at every instant,

$$m_A dV_A = m_B dV_B$$

We notice that $m dv$ is big when the elastic is stretched a lot, and may introduce the idea of the force pulling on both trucks at an instant. To do this we play a

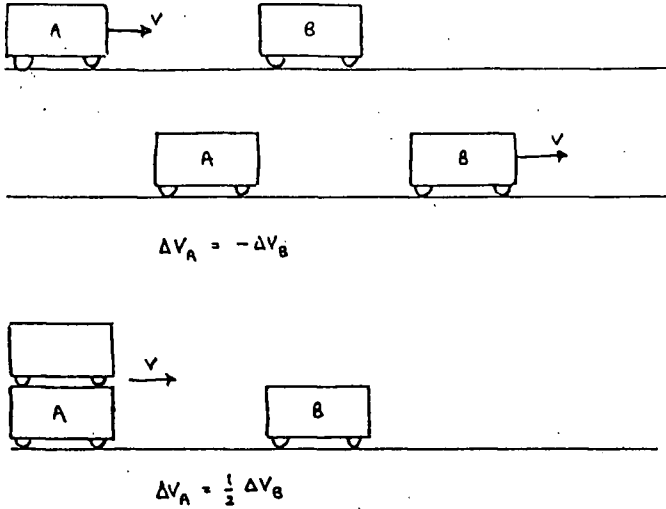


Fig.6
Collisions between trucks
(a) identical trucks (b) one twice as big as the other

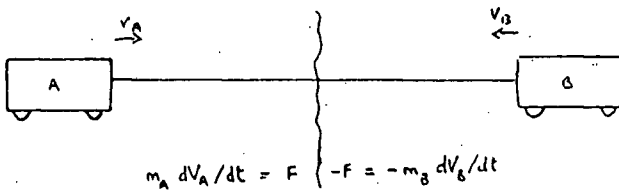


Fig.7
A 'slow' interaction using elastic

very important theoretical trick: we imagine the elastic cut in two and just think about the motion of one truck whatever is on the other end of the elastic. Thus we get a pair of forces which are equal and opposite if we define.

$$m_A \, dV_A/dt = F$$

$$m_B \, dV_B/dt = -F$$

In this way Newton's third law is introduced in a way which shows how momentum conservation is the basic experimental fact, from which the third law derives if the abstract idea 'force' is introduced. Notice how all this is in fact closer to modern particle Physics than is the traditional teaching of dynamics, in that momentum survives relativity as an important quantity while force does not, and that interaction between objects becomes the basic dynamical entity.

More important, it may be that kick dynamics, followed by collision dynamics, and only then by steady forces and accelerations, does less violence to childrens' - and our - natural dynamical intuitions, while bringing out sharply where the new dynamics differs. Physics in general and dynamics in particular is uncommon sense.

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