COMPILATION: Unit 3 - Newton's laws demos - conceptual confusions. Part 2

The "karate chop" and 'bed of nails" demos are discussed in this continuation of the PHYSHARE thread.

Date: Sat, 27 Jul 2002
From: Ron McDermott <rmcder@peoplepc.com>
Subject: **Hand, brick, which breaks <g>**?

Ok, no one jumped in to respond to my inquiry as to how we explain this phenomenon to kids so they don't retain their inequality misconception regarding Newton's 3rd Law, so I'll take a stab at putting down what I think and/or surmise, and let some of you snipe at it:

Ok. Hand strikes brick/board/whatever. Hand is more flexible than other object, which is perceived to be rigid. Very large impulsive force applied equally to both objects (3rd Law). Object breaks, hand doesn't (ideally <g>). Why?

Presumably, rigid object is also brittle and can shatter given sufficient displacement of structure. Hand applies force, which accelerates material directly in contact with hand downward (compression). This effect propagates through the rigid material until it reaches the other side. I think that previous layers of mass come to rest as successively lower layers of mass are accelerated, and if so, the applied force is undiminished as it propagates (this would be a significant factor, I think). The acceleration at the bottom side produces a stretching or tearing effect that exceeds the tensile strength of the material and it "tears" successively (upward). Once the object breaks, the object can no longer resist to the same extent as previously, so the forces (on hand and object) drop significantly. Seem ok to everyone?

Ok... So, the same kind of thing is happening in the hand, but although able to flex more, the hand WILL flex more. So there's a question of whether we get a net "gain" there or not. Is the propagation delay less or more for the flexible material? My inclination is to think that rigid implies faster, and if this is true, it would suggest that destructive forces may not be able to reach sensitive areas before the rigid object breaks. This has been my argument in the past. However, thinking this through now has led me to another possibility (or maybe a contributing factor).

It occurs to me that the layers of mass in the hand probably DON'T come to rest as successive layers of mass are exposed to the propagated force, so that the force diminishes as it propagates through the hand. By the time it reaches sensitive areas, it will have been reduced (significantly?).

Anyway, that's where I am with this, and I'd really appreciate ideas on this. I think this is a vital discussion to have with kids, because if we do not confront this issue, kids are never going to really accept the 3rd Law. I think it's essential to meet it head on! Ok. Fire away.

Date: Sat, 27 Jul 2002
From: "Donald E. Simanek" <dsimanek@lhup.edu>

Ron, did we let you down?

One of the better website discussions of the **Karate chop** is at
http://www.discover.com/may_00/featphysics.html .
But I haven't yet found a site which gets at the real physics I want to hear about.

One often sees the factoid that bone has can withstand 40 times more stress than concrete. Relevant? Damage to hand can also occur at joints between finger bones. What stress can they endure?

Another factoid, the hand can hit the brick with a speed of 11 m/s=24 mph. The Newton's Apple site then says that the hand can exert a force (maximum, I suppose, during the impact) of 3000 Newton = 675 lb. But it's the impulse that's important to break the brick.

It's important that the blow be sufficient to actually break the object, for breaking takes a large amount of the kinetic energy. If you hit the object with the same velocity and it didn't break, you'd really feel it.

Some experiments are suggested. I suspect other factors play important roles. The experiment with boards is generally done with very dry boards (baked in an oven sometimes) and cut and placed so they are supported at two edges and the grain is parallel to those support edges. Wood breaks easiest parallel to the grain.

Take such a board. Take a broomstick and hit the board in the middle. Likely it will break, the broomstick will not. Now lay such a board so its grain is the other way with respect to the supports, i.e. the carpenter's "grain end" is at the supports. Likely the board won't break this time, unless you really hit it hard. Wood is an interesting material. A cedar slat in my lawn chair broke yesterday just from sitting on it. (No, I'm not THAT overweight.) It broke across the grain. Close examination
showed (1) the wood was desert-dry from being outside on a porch for many years, (2) there was a knot near where it broke, making an area of weakness. The break was very ragged.

Bone. Find an old-fashioned butcher shop which might give you a fresh animal bone. Try breaking bricks and boards with it.

Experiment. Does the "tensile" strength of the two bodies matter more than the area of contact? Try bridging a brick or concrete slab across two supports. Now hit its center with the SHARP EDGE of another similar object. Which breaks? Why are you not surprised?

Karate demos you see on TV are often done with a stack of boards. They are cut so that the grain can be oriented advantageously. They are stacked with small wooden spacers under the ends, so the boards of the stack aren't in contact. This makes the trick a lot easier. Why is that, from a physics point of view?

Some folks say that the calluses which Karate practitioners build up on their hands (from repeated practice and failures) help them withstand the impact. Could there be anything to that, or is that just idle speculation?

Breaking a brick held in the hand, using a hammer. Resilience and flexibility of the hand may play a role. Some demonstrators put the brick on the top of their head (solid bone) and break it. Not much flexibility and resilience there. Do not try this if you are allergic to skull fractures. Insist that the person who recommends it demonstrate it on himself in your presence to show you how it works.

Hmm. Wonder what would happen if you bridged a board with its ends supported by several raw eggs. Could you break the board without cracking the eggs? I'll bet you could if the board were long enough, and not too thick. You could set the eggs point down in little cups with some resilient material around the cup edge (to conform to egg irregularities). Then the eggs wouldn't roll off the table after the break. Potentially messy business. The karate trick is often done with two people holding the edge of the board.

I agree with Ron that we need to consider propagation of stress through the material. Glass, when hit by a bullet, fractures in a particular way, with a cone-shaped hole, smaller on the incident side, larger on the exit side. The cone-shaped profile is reminiscent of the shock wave of a airplane moving faster than the speed of sound, and the underlying reasons are the same.

To me, it seems another example of attempting to demonstrate physics principles with a situation which has far too many messy details to do the job without spending inordinate amounts of class time on the task. **There are many cleaner demos of Newton's third law, and of conservation of energy and momentum, without getting involved in issues of strength of materials.**
Although I was the first at our school to build and demonstrate the **bed of nails demo** of breaking the concrete block on one's chest while lying on the nails, I'm rather sorry I built it. For others loved to use it in class for its "dramatic" impact, but I couldn't see that the students got anything out of it but a little entertainment break from the boring physics lecture. For that reason I NEVER used it in the classroom in a physics lecture. I judged it had no educational value in an introductory course. In an engineering strength of materials course, maybe.

Ron fears that if we don't explain this sort of thing, kids will never accept Newton's third law. I suppose there may be something there we need to address. It is true that the conservation of momentum arises from Newton's third law. That is, without the 3rd, you couldn't derive the momentum conservation law. So the third law is clearly essential. Most students probably haven't seen the momentum law derived, so they don't see the connection. That's why **all of the demos posted here which claim to be "demos of the third law" are really "demos of the conservation of momentum law.**

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Date: Sat, 27 Jul 2002
From: Tom Hammer <thammer302@earthlink.net>
Priscilla Laws and her colleagues at Dickinson College Physics Dept. have done some very nice work in Workshop Physics on this topic. They have a good lab worked up and have developed some nice apparatus which can be purchased, from PASCO, I believe, for your lab to measure the breaking force of the board, and I believe, the amount of energy required. Then students calculate, approximating the mass of the hand-arm system, the energy of the arm required and thus the velocity of the arm that one needs to obtain. Then they have students break a board in the lab!
Tom Hammer
Hockessin, DE

Date: Sat, 27 Jul 2002
From: John Mallinckrodt <ajm@csupomona.edu>

Donald E. Simanek wrote:
>... It is true that the conservation of momentum arises from
>Newton's third law. That is, without the 3rd, you couldn't derive the
>momentum conservation law. So the third law is clearly essential. Most
>students probably haven't seen the momentum law derived, so they don't see
>the connection. That's why all of the demos posted here which claim to be
>"demos of the third law" are really "demos of the conservation of
>momentum law.

Indeed. I maintain that Newton himself expressed the third law as he did in terms of "actions" rather than as "conservation of momentum" *only* because, to Newton, forces were "more fundamental."

Conservation laws didn't come into vogue for another 150 years. Nevertheless, the Principia makes it clear that the third law has its *source* in Newton's observation that the total momentum ("motion" to Newton) of colliding bodies is not altered by the collision and the obvious implication that can be drawn from combining that observation with the second law.

It seems to me that it makes pedagogical sense to replace the third law (which often seems ridiculous to students) with the law of conservation of momentum (which generally seems almost obvious) and
to *derive* the third law rather than vice-versa.

Some might recoil at losing the historical connection to Newton's laws, but a careful reading of the relevant passages in the Principia will reveal that we did that long ago. Newton's laws are all about impulse (which was synonymous with "motive force", "impressed force", and "action" to Newton) and momentum (synonymous with "motion") and not at all about acceleration or (what *we* call) force. I offer the originals, my translations of the "originals" (according to Motte/Cajori), and a recasting into simple modern terms that express the same content.

Law I
(Original) Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.

(Translation) Every body maintains its vector momentum, whether zero or otherwise, unless it is compelled to change by the application of external impulses.

(Recasting) **In an inertial frame of reference (to which subsequent laws refer), the momentum of a body is conserved unless it is subject to an externally applied impulse.**

Law II
(Original) The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.

(Translation) The change in the momentum vector is proportional to the applied impulse vector.

(Recasting) **In any given period of time, the change in momentum of a body equals the externally applied impulse.**

Law III
(Original) To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

(Translation) For every impulse vector there is an equal and opposite impulse vector--to be more specific, the mutual impulse vectors of two bodies upon each other are equal and opposite.

(Recasting) **In any given period of time, the impulse of one body upon a second is equal and opposite to the impulse of the second on the first.**

As I have often argued, acceleration appears to have been a very difficult concept to Newton. Understanding this may cause us to view our students with a bit more sympathy (and, perhaps, to change our pedagogical approaches.) Newton was *far* more comfortable in talking about chang*es* in momentum (and, therefore, chang*es* in velocity) caused by impulses than he was in talking about chang*ing* momentum (and, therefore, chang*ing* velocity or acceleration) due to continuously applied forces. His geometrical arguments for the trajectories of bodies were based upon adding up the effects of an infinite sequence of infinitesimal impulses, not (for obvious reasons!) on solving a differential equation relating the second derivative of position to the applied force. Although they may amount to the same thing and lead to the same results, the conceptual differences are enormous.

One more related example: We rail against naive concepts that we imbue a rock with "force" when we throw it, but Newton would have been far more sympathetic. He spoke of "vis insita" or the "innate force of matter" which was at least conceptually similar if not identical to his "motion" (momentum) and he understood that the "vis insita" was altered by "actions." Why not take advantage of students' innate understanding of this simple--and essentially correct--concept?

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Date: Sat, 27 Jul 2002
From: John Mallinckrodt <ajm@csupomona.edu>

Donald E. Simanek wrote:
>... The Newton's Apple site says that the hand can exert a force
>(maximum, I suppose, during the impact) of 3000 Newton = 675 lb. But
>it's the impulse that's important to break the brick.

I think it's more complicated than this. I can believe that it isn't *simply* the force since a large force quickly applied might be able to invoke internal dynamics in the brick that the same force gradually applied does not. But it certainly can't be *simply* the impulse either since I can deliver an arbitrarily large impulse to the brick without breaking it by, for instance, setting another brick on top of it for many years.

What breaks the brick is internal strain and the resulting stress. Stress varies from place to place in the brick and can be a somewhat complicated function of where forces are applied as well as the time-dependence of those forces. (Consider, for instance, the "**breaking the wine glass demo**"; small forces with a carefully adjusted time dependence cause enormous stresses that break the
glass.) Furthermore the breaking stress will vary from place to place in the brick due to inhomogeneities.

>... Experiment. Does the "tensile" strength of the two bodies matter more than
>the area of contact. Try bridging a brick or concrete slab across two
>supports. Now hit its center with the SHARP EDGE of another similar object.
>Which breaks? Why are you not surprised?

Right. More evidence for the stress mechanism.

>... I agree with Ron that we need to consider propagation of stress through the material. ...

Me too.

Date: Sat, 27 Jul 2002
From: Ron McDermott <rmcder@peoplepc.com>

I agree with you here, John. It's interesting to note that what we take as a naive misconception "force can be transferred to an object and it is THIS which compels its motion" - impetus - is far less laughable if we substitute the terms "energy" or "momentum" for "force". What we see as a misconception has roots that are logical and understandable if we accept that a student is simply using the terminology incorrectly. So it isn't the IDEA that's poor, but the terminology. And yes, we could build on that "misconception" rather than proclaiming it "wrong".