

I think Frank Wilczek is too harsh when he implies that the use of equations like $F = ma$ is a matter of intellectual inertia. In practical terms, in engineering, and even in the design of physics instruments, we are interested in the values taken by certain variables x_i and the known dependence is in the form of differential equations $dx_i/dt = v_i$ and $dv_i/dt = f(x_i, v_i)$. When x_i is some position, the last is a form of $F = ma$. Many physicists—David Bohm and John Stewart Bell, for example—have argued that position is the fundamental variable . . . hence the importance of $F = ma$.

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Frank Wilczek's column exposes a delicate point in physics teaching. Good teachers avoid implanting misconceptions to be overwritten later. Yet Newtonian mechanics courses do just that! During 20 years teaching I've maintained that Newton's three laws are neither good laws nor independent. Students enjoy hearing the first law is just as circular as it seems. Textbook apologies that falsely limit physics to inertial

frames contradict later teaching that physics can be used in any coordinates. Perhaps the first law was just a political device to start discussion, and to divide Newton's detractors. The third law is necessary for beginning physics of ropes and pulleys, but is wrong as "principle": Momentum conservation via translational symmetry has myriad solutions. The second law is okay, but it is indefensible to promote Newton's emphasis on "force" as primary, only later to revise it with Hamilton's equations of greater scope. Eventually I evolved a refreshing approach to non-calculus physics with energy and conservation laws as primary, and it works well.

Students happily accept that Newton sometimes guessed wrong. A timid teaching culture and careless textbook writing create the intellectual inertia Wilczek observes. Good physics teachers need to demonstrate critical thinking, distribute their own notes, and have the courage not to brainlessly repeat what is written in the book.

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Wilczek replies: Ramamurthy Ravi's letter is an excellent, scholarly supplement to my October column, which emphasizes that some classical masters of mechanics had logical and aesthetic misgivings about the force concept, even before modern physics began to push us strongly toward different ones.

Regarding Brent Meeker's letter, my critique was meant to be directed at foundational issues including, specifically, which principles should be regarded as primary, and which as derived. There are some significant problems with using $F = ma$ as a primary principle, as I discussed. They could be avoided, perhaps advantageously, by focusing on momentum and energy. Of course, in that approach it would still be appropriate and extremely useful to have $F = ma$ as a derived equation, with its limitations indicated. Some intellectual inertia isn't necessarily a bad thing, if it keeps you moving in the right direction and allows you to remain in sync with long-established flows.

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