BRIDGE
Project Summary
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Gary Pajer
Assistant Professor of Physics

Class:

PHY 200 General Physics I
Calculus based introduction to physics.
Required of physics, math, and chemistry majors.
About 50% science majors and 50% education double majors.
Enrollment: 26

Problems and questions:

There are several well-known obstacles interfering with the progress of the beginning physics student. One of these is the conceptual understanding and application of Newton's third law. In an introductory physics class students are asked to assimilate and organize an array of new concepts while at the same time they are asked to unlearn their preconceived notions and their poorly grounded vocabulary. Newton's third law is traditionally a tough spot. The students are just starting to make sense of the concept of force and Newton's second law, but Newton's third law sounds rather similar with its talk of forces and interactions. Students have trouble distinguishing the third from the second law, and rarely grasp the significance of the third law. It was my hope to find a way to remedy that situation.

Gaining information:

In preparing myself, I consulted the standard physics education research journal and two standard monographs on the subject of physics pedagogy. These served to sharpen my focus on what I had already observed, and to illustrate that the misunderstanding was universal. I distilled the collected observations and insights trying to find a single principle that might simply account for student difficulties and provide me with a single target for a new approach. One place students seem to have difficulty is in understanding that Newton's second law is a statement about forces *on a single object* while Newton's third law is a statement about forces *between a pair of objects*. I speculated that perhaps if that distinction could be emphasized and made clear then the students might have an easier time organizing the concepts in their minds.

Newton's Laws

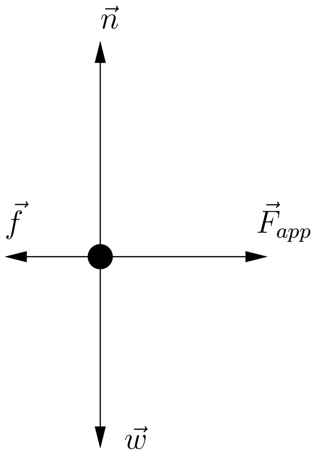
The First: In the absence of a net external force, an object will move in a straight line with constant speed (possibly zero).

The Second: When a net force acts on an object, it will cause the object to accelerate in the direction of the net force. The magnitude of the acceleration is proportional to the magnitude of the net force, and inversely proportional to the mass of the object.

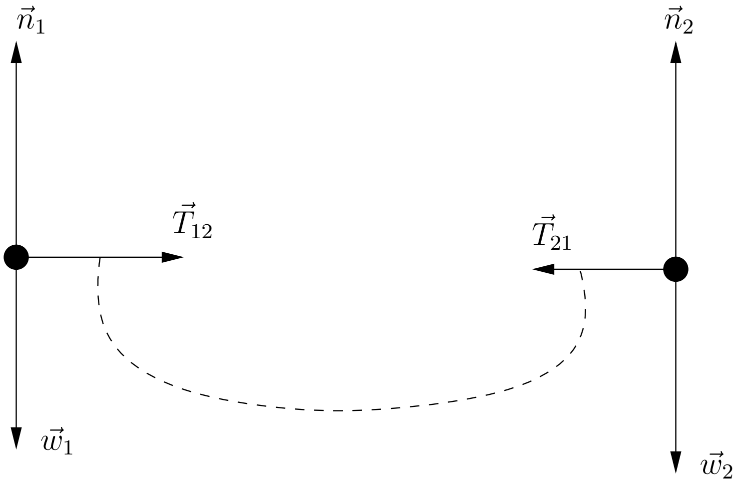
The Third: If one object is exerting a force on a second object, then the second object is also exerting a force back on the first object. The two forces have exactly the same magnitude, but act in opposite directions.

The idea:

I thought a graphical representation of Newton's second and third laws might illustrate the distinctions and give students something to remember when thinking about a physics problem. A standard graphical representation called the Free Body Diagram (FBD) already exists for illustrating Newton's second law. It is common among novices to try to use the FBD in situations where Newton's third law applies, but fail to do it correctly. Part of the cause of the confusion is that problems are often presented that require the use of *both* the second and the third law. When both laws are in play, beginners stumble. I noticed that the graphical FBD could be extended to illustrate Newton's third law. The representations of the two laws would be very different and easily distinguished giving, I hoped, the students a memorable way to think about them. The two types of FBD are illustrated below.



Free Body Diagram



Extended Free Body Diagram

In each diagram, the black dot represents the object in question. It is hoped that the clear distinction of having either one or two black dots in the diagrams would serve as a clear reminder of the distinction that the first represents Newton's second law, and only one object is under study, and that the second diagram represents Newton's third law which applies to pairs of objects.

Assessment:

The physics community is fortunate to have a *de facto* standard assessment instrument for use in introductory mechanics courses. The Force Concept Inventory (FCI) has been available for about ten years, and has been applied by many instructors in many learning environments. Out of approximately 30 questions, four are specifically directed toward testing understanding of concepts associated with Newton's third law. I chose to adopt the FCI. I administered it as a pre-test on the first day of class (but I didn't tell them that they would see it again), and again during the last week. For the BRIDGE project, I abstracted the data for only the four questions pertaining to the third law.

Did it work?:

Pre/post FCI results on questions relating to Newton's third law are shown below. Summary: situation encouraging, but a bit murky.

		Question 4	Question 15	Question 16	Question 28	Whole test
Rider	pre	28%	24%	56%	24%	36%
	post	96%	83%	92%	83%	58%
	'gain'	94%	78%	81%	78%	35%
HSH	pre	17%	14%	56%	22%	28%
	post	90%	79%	93%	99%	64%
	'gain'	88%	76%	84%	99%	62%
ASU	pre	26%	7%	37%	19%	34%
	post	77%	47%	89%	68%	63%
	'gain'	69%	43%	83%	60%	44%

Rider: PHY 200, fall '04
HSH: High school honors physics
ASU: An "intermediate" physics course at Arizona State University. (Non-calculus prep for the regular calculus-based sequence.)

The HSH and ASU categories chosen are the closest courses to our PHY 200 for which I have found detailed results.

'Gain' is what Hake calls "normalized gain", the ratio of (post – pre) / (100% - pre).
It is a measure of improvement, expressed as a fraction of the maximum possible improvement. For example, if a student scores 50% on the pretest and 100% on the posttest, her normalized gain is 100% (she improved by the maximum possible amount). If she scored 75% on the posttest, her normalized gain would be 50% (she improved her score by 25%, half of the maximum possible).

The scores show gain for Rider students in the questions relating to Newton's third law. The gain is commensurate with, or better than, the gains of the two comparison populations. Something positive happened. Furthermore, the gain among Rider students for questions related to the third law is considerably larger than the gain among Rider students for the test as a whole. The control groups also showed enhancement of third-law scores relative to whole-test scores, but not as much of an enhancement as the Rider group.

There were not enough controls built into this small experiment to allow attribution of all of the gain to the use of the extended FBD. There were confounding elements. One interfering event was my assignment of a particularly challenging homework assignment on the subject. Unexpectedly, most of the students came to me outside of class to ask for help on that homework. Consequently, almost everyone in the class enjoyed individual or small group attention related to Newton's third law. On the other hand, small group attention occurred throughout the semester on a variety of topics, yet the gain on the third-law questions relative to the test as a whole (probing *other* physics concepts which *were* covered in small group settings) exceeds that of the control groups. One cannot be certain that the performance improvement came from the use of the extended free body diagram rather than from individual attention, but the evidence is suggestive that it is.

From here:

I want to take a ninety-degree turn. Independently from the BRIDGE experience, I became aware of an alternate approach to introductory physics, one that gives primacy to the important physical principles of conservation of momentum and conservation of energy. The traditional ordering starts with the mathematical description of motion, and concludes with the conservation laws. The student does not end up with enough time to appreciate the power of those principles, while arguably wasting time early in the semester learning math rather than physics. The alternate approach reverses the order, adding the mathematics of motion only where needed, as needed.

The extended free body diagram, as well as the original free body diagram itself, attempts to provide students a visualization of physical concepts. Many physics teachers argue that *all* physics concepts are fundamentally geometrical, and best suited to visualization for proper understanding. The more traditional approach to organizing the introductory class emphasizes algebraic manipulation rather than geometrical visualization. I feel that the introduction of the graphical free body diagrams was a bit out of context with the surrounding algebraic presentation. I hope that the new approach to organization will reduce the emphasis on brute algebra so that the use of graphical aids will fit in more naturally.

In addition, BRIDGE has exposed me to many creative ways of doing formative assessment. I'm not aware of any assessments of that type being used in physics. I'm intrigued by the possibilities. I can almost see a different kind of physics class, one with assessment tools married to learning tools. The classroom atmosphere might be very different from what it is today.

As an example, consider CAT 12, "Analytic Memos", from p. 177 in *Classroom Assessment Techniques* by Angelo and Cross. The instructor presents a statement of a physical phenomenon. The students respond in writing presenting comments on the ambiguity of the statement, comments on the use of terminology, a complete physical analysis (including diagrams), a discussion of the physical principles involved, and a mathematical analysis. A blank structured outline might be provided during the early part of the semester, but by the end the students would be expected to be able to operate on their own. The statement might be correct and clear, or it may be incorrect, poorly worded, ambiguous, etc. The statement might be, for example "How much force is needed for a roller-coaster to successfully complete a loop-the-loop?" A good response requires good general analytical skills, good understanding of physical concepts, good understanding of physical laws, the ability to find correct physical relationships among the concepts and objects in question, the ability to take the deconstructed pieces and synthesize a proper description in the language of mathematical physics, etc.