OAPT Newsletter

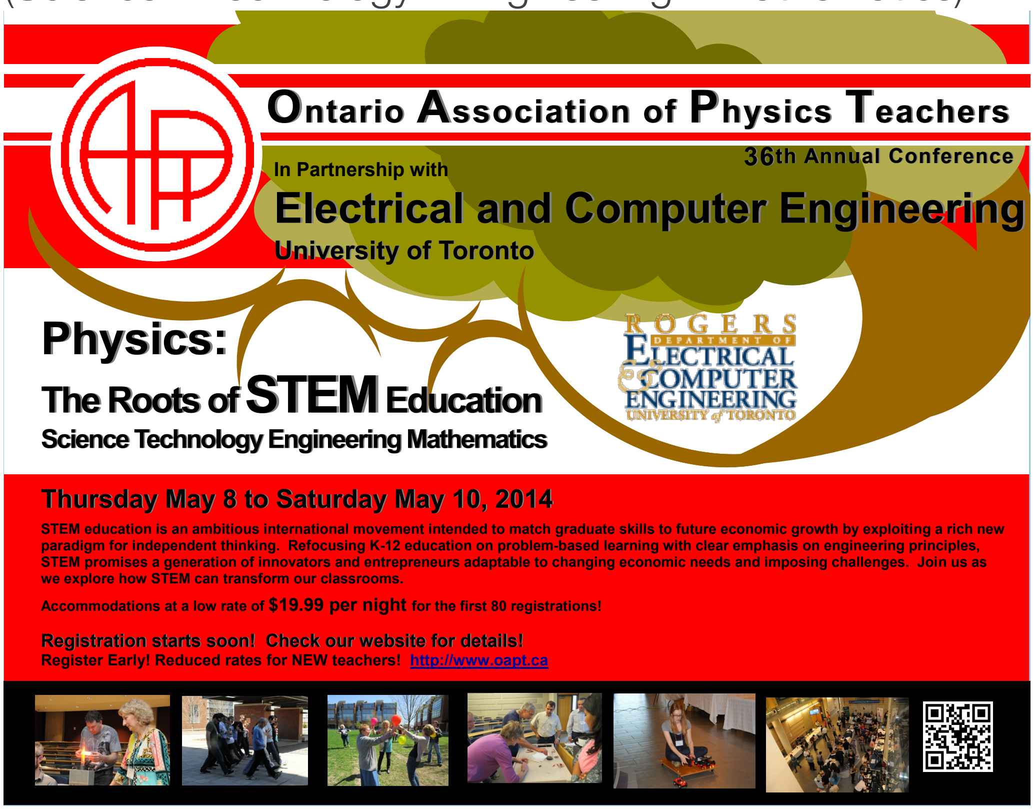
Winter 2013

Ontario Association of Physics Teachers

Contents

2014 OAPT Conference Theme: STEM Education

(Science – Technology – Engineering – Mathematics)



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Accommodation only $19.99/night for the first 80 registrants!

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Articles

Physics Mindset and Anxiety

Chandra Boon

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When I studied physics I found the most challenging concepts were the also most interesting and motivating. It was a shock to me when I began teaching physics and realized this is not a universal experience! For many students anxiety about physics begins even before they walk into the classroom on the first day. They've heard that physics is "so hard". For others the anxiety hits the first time they encounter a problem or a concept that requires serious processing to understand. For some bright students, having to make an effort to understand something new can be an unfamiliar experience and may lead to feelings of helplessness. Studies have shown that bright girls, in particular, are prone to a helpless response to challenge (Dweck, 1999, p. 54). came to realize that I could design the most engaging lesson to share the most fascinating physics concept, but anxiety about the challenge could prevent students from learning. I began to search for a way to help students overcome anxiety and work through difficulty, and perhaps even enjoy the challenge of learning physics.

When students understand how the brain forms and retains connections, they view practice as a necessary step in their learning.

I have found two different realms particularly helpful: neuroscience and social psychology. Understanding the physical basis of learning from a neuroscientific perspective provides fundamentally important insight into the learning process and the physiology of stress and anxiety. In simple terms, when the brain learns, new connections are formed between neurons and memory is the retention of these new connections. Pathways that are not used are pruned by the brain, whereas practice of newly learned material serves to reinforce pathways. Reinforcement of pathways leads to greater likelihood of retention. In addition, anxiety during the learning process provides competition for cognitive resources and can affect retention. When students understand how the brain forms and retains connections, they view practice as a necessary step in their learning.

I learned about important work that has been done in the field of social psychology after reading *Mindset and Self-Theories* by Stanford professor Carol Dweck. Mindsets are beliefs people maintain about themselves that shape their thoughts and actions. Dweck identified two basic mindsets: the fixed and growth mindsets. The fixed mindset is based on the belief that your traits, such as intelligence, are fixed. The growth mindset is based on the belief that your traits can be changed or developed through experience and conscious effort. Dweck's research has revealed that people with a fixed mindset tend to avoid challenge because they equate it with a lack of ability. People with a growth mindset view challenge as the route to increasing their intelligence. Dweck has also shown that the growth mindset can be learned. Studies in the field have also shown that adopting a growth mindset leads to a reduction in anxiety, such as fear of failure. I came to understand the way students' beliefs about their physics ability shape their interpretation of their learning experience and can either induce or reduce anxiety.

Ultimately, I decided I needed to try to equip students to cope with the emotional impact of being challenged by physics. I decided to teach some basic neuroscience and the growth mindset and systematically examine how students were affected. I designed an action research project based on the question "How does teaching a growth mindset affect anxiety in grade 10 girls studying grade 11 physics?" The project involved teaching students about how their brains learn and the mindset framework to help them understand learning as a physical process. I tried to assist them in reframing challenges as a necessary component of their development and growth. When neuroscience is combined with mindset, students see that brain structure is not fixed and it becomes clear to them that the fixed mindset is based on a false belief. Students come to understand that their thinking can either lead to the development of their potential or limit it. In addition, my physics students became participants in the research by working as "mindset mentors" with grade 8 students who were preparing to write their first set of final exams. The physics students taught the grade 8s how to view this challenge as an opportunity to develop as learners and exam writers. By mentoring the younger students, the grade 10s more fully internalized the mindset principles. In interviews and surveys students have told me that by practising the mindset principles they feel greater enjoyment in physics and they no longer feel they have failed when they struggle on assessments. They have shifted their focus from performance to development. One student said she realized there was “nothing to fear, only things to discover”. Based on the results of the action research project, teaching neuroscience and the mindset framework have become integral aspects of my physics pedagogy.

Chandra Boon teaches math, science, and physics at Branksome Hall, an all-girls school in Toronto. Chandra has recently begun a PhD in Education at OISE/UT with a focus on applications of affective neuroscience to science education.

References

Dweck, C. S. (2000). *Self-Theories: Their Role in Motivation, Personality, and Development.* New York, NY: Taylor & Francis Group.

Dweck, C. S. (2006). *Mindset: The New Psychology of Success.* New York, NY: Ballantine Books.

TLLP Action Research

Lisa Lim-Cole

Uxbridge Secondary School

Making changes in a school is a difficult task. In fact, most of the time, we work individually to plan and deliver lessons. We grade student work and we complete the jobs that require us to monitor our students. My role as department head has become a role that seems confined to the daily routines of ordering materials, completing paperwork, attending meetings and letting people know what the “new initiatives” are within the building. Trying to figure out what impact I can have in the building I work it has been a challenging one. How do I help teachers? How do I provide opportunities for science teachers to truly collaborate? Where is the time to do this?

This past school year I and colleagues Angela Davis (Chemistry/Physical Education) and Stephanie Hale (Biology/Chemistry) collaborated to examine our instructional practices. Support for our action research was provided by the Teacher Leadership and Learning Program (TLLP). The TLLP is a Ministry of Education program supporting teacher-led initiatives in partnership with the Ontario Teachers' Federation. Through the TLLP grant we were able to study "Cooperative Group Problem Solving, Inquiry Based Learning and 21st Century Skills in Science". Our plan was to examine the structures that Physics Education Research suggests for the improvement of physics education with a view to using them for the instruction of science in other disciplines. We quickly realized that the core skills needed to implement changes in our classroom structures required a careful orchestration of skill development starting from Grade nine.

The Ministry of Education has extended our project to enable us to work as a science department to implement our strategies. The project is now considered a Provincial Knowledge Exchange Program. Come to the OAPT conference and ask me how to get your own action research funded!

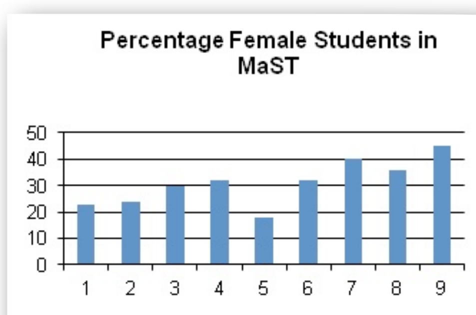
Increasing Female Enrollment

Roberta Tevlin

Danforth CTI, Toronto

For the past nine years I have been deeply involved in the Math Science and Technology (MaST) program at my school. Our school is 70% male, so we weren't surprised that in our first few years we only had 23-32% female students entering the program. When this dropped to 18% in our fifth year we made some program and procedural changes that we think have caused a fairly steady four-year climb to 46% female students in our grade nine class this year.

Here is how it happened. We followed the example of Physics Education Research and first listened to the students. We got all the female MaST students together after school (luring them with free pizza!) and had them fill out surveys and then discuss questions in small and large groups. Two big changes came out of this:



1. Grade nine MaST students were being asked to choose either drama or music as an elective. On our survey half of the girls reported that neither of these electives had appealed to them, that they would have preferred visual arts! We can only guess how many girls may have rejected the MaST program for this reason. We now offer art as an elective and provide many more activities encouraging artistic expression in math, science, and tech courses.
2. Many girls admitted being strongly influenced by peer and worried about appearing to be "nerdy". They felt that they could help counter this influence by visiting their former middle schools and talking to the grade 7–8 girls. They did so and now we also make sure that half of our assistants during MaST events are girls. The senior girls have become proud of their place in the program and their role in changing one small part of the world for the better.

In the spring we run a mini skills competition. Eight of our feeder schools are invited to send selected grade 7 students to us for the day. The first year I ran my event, an engineering design competition, all of the competitors were male! Since then I have made it a female-only competition. This has been hugely successful! It influenced the girls' teachers as much as it did the girls themselves. When they saw their female students fully engaged in drilling, sanding, talking, decorating and competing they were moved to encourage specific female students to apply to the MaST program. What I have learned is that it is still not a gender neutral world with regards to girls and science. We all need to explore all angles.

PER Corner

Teaching Forces PERsuasively II – Laying Down the Laws

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Newton's laws are tough. But back in the day when I used to wear a tie to work, I thought I did a great job teaching these laws. With great care I spent one whole day on each law. I had lots of lively demonstrations and funny stories to tell about spherical cows and shoe rockets. But you don't know what you don't know (to paraphrase Donald Rumsfeld) and it turns out there was a lot that I didn't know about how my students learned Newton's laws.

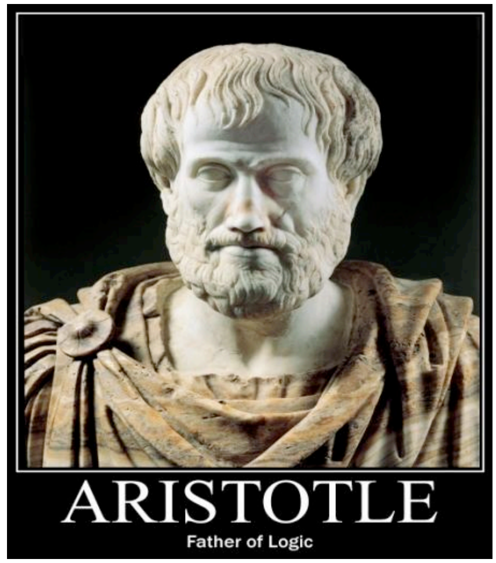
Don't be so dense!

There is not much that is intuitive about Newton's laws. Don't be seduced by the elegance and power of these three laws according to your experienced and expert perspective. Their framework is logical once you buy into it, but looking at force and motion without Newton's insight is very challenging. Just ask Aristotle (or his mom, who kept his report cards).

ATHENS HIGH SCHOOL
Final Report Card

Student Name: Aristotle

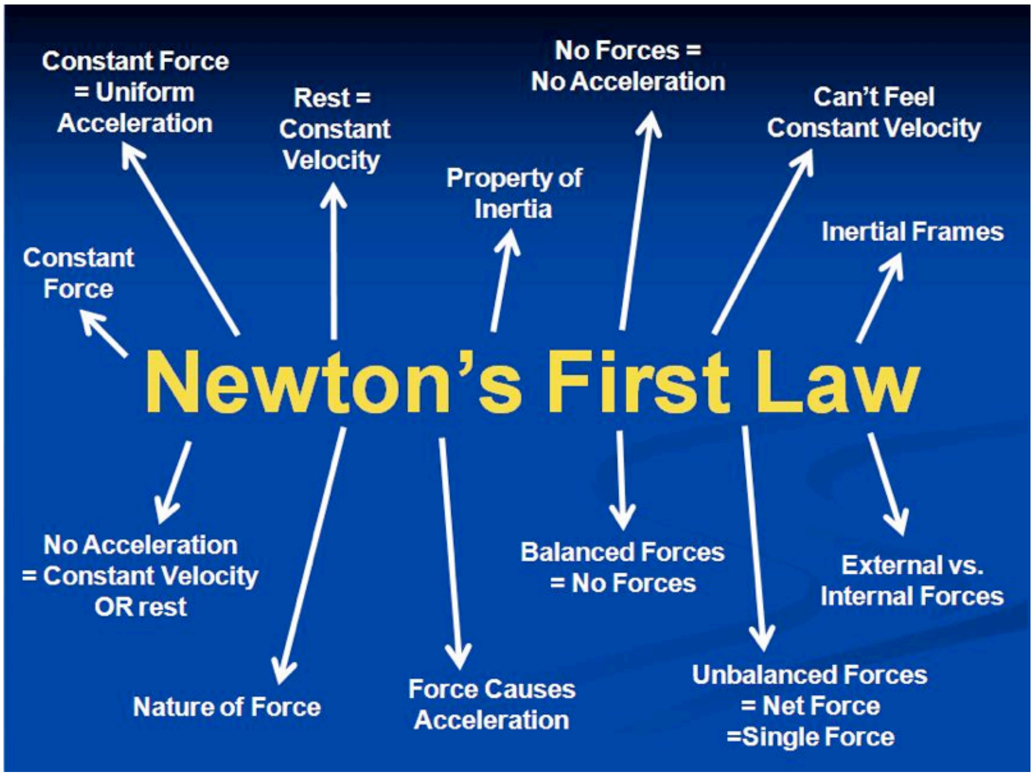
Subject	Grade
Logic	A+
Nicomachean Ethics	A+
Poetics	A+
Newtonian Mechanics	D –



Newton's laws are conceptually very dense. Each law is rich with concepts and cannot be mastered, or even vaguely understood, until each concept is carefully met and dealt with. As physics coaches, we can't properly train our students until we give them the chance to unpack the laws and explore them in detail. This requires a considerable investment of time compared to my old three day whirlwind tour. Thinking back to those tie-wearing teaching days, at the time I did remark that my grade 12 students had difficulty with physics problems not because of the challenges of pulleys or frames of reference, but because they didn't understand the "easy" stuff, the first law. I now understand that this wasn't due to lack of effort on their part. (No one would accuse Aristotle of lack of effort). I simply had not provided them with the right opportunities in which to learn. Now I spend about four days helping the grade 11s build the first law alone.

Blowing law chunks

Let's borrow a handy idea from psychologists called "chunking": taking a complex data set or idea and breaking it down into smaller, more manageable parts that help you to better understand or work with the whole. Mathematicians do this all the time, creating systems of lemmas and corollaries that orbit a central theorem. As physics teachers we need to unpack each of Newton's laws and break down its ideas or implications into meaningful, digestible parts.



The first law: the catalogue

I find the first law to be the most conceptually dense of the three. A thorough high-school level understanding of it depends on a slew of wide ranging ideas. I call one chunk of the first law the **catalogue of force-motion relationships**.

The First Law Catalogue of Force-Motion Relationships

No Forces	⇒ *rest* or *constant velocity*
Balanced forces	⇒ *rest* or *constant velocity*
Single force	⇒ *acceleration*
Unbalanced forces	⇒ *acceleration*

None of the items in this catalogue are obvious or intuitive. It took many people many centuries to find these relationships. A student's intuitive catalog of force-motion relationships would look more like this:

The Intuitive Catalogue of Force-Motion Relationships

No forces	= *comes to rest* or *at rest*
Balanced forces	= *certainly at rest*
Single force	= *steady motion*
Unbalanced forces	= maybe *acceleration*, maybe *steady motion*

Students need to deliberately analyze each of these force-motion relationships and draw these connections. This takes two classes for my students. I call another handy chunk **the net force principle**. When we study the combined effect of many forces acting on a system we routinely think of the system behaving as if it were subject to one single force, the net force. This is an idea so obvious to us experts that we seldom bother to articulate it. Features like this are often called *the hidden curriculum*. Teachers typically expect students to pick up on the hidden curriculum through practice and familiarity. This seldom happens, leaving students conceptually handicapped.

One final chunk connected to the force-motion catalogue is an idea describing the change between the force states. I call this the **force-change principle**. When the forces change (for example, from balanced forces to unbalanced forces) the motion changes simultaneously. There is no lag or delay. When we push a box with a constant velocity and then remove the pushing force, the box doesn't continue on for a while (Aristotle's impetus theory) before friction kicks in and the slowing begins. (Homework: ask your students to describe in detail what happens in this situation. Their answers are often interesting!)

There is a chunk of the first law that perplexes me: inertia. First of all, I'm not sure why the first law is a law of inertia (reader feedback, please!). The catalogue of force-motion relationships seems pretty complete to me without a mysterious "inertia" thrown in; these ideas don't depend on the amount of stuff or matter involved. As long as we are not talking about "light" (massless) objects the full catalogue is valid. Secondly, the typical definition of inertia is not helpful: the "resistance of an object to a change in velocity". What exactly does this mean? Does "resistance" mean that inertia prevents a change in velocity? Does it mean that inertia has to be overcome, like a force of static friction, and then velocity begins to change? How would an intelligent non-physicist interpret that definition? There is nothing that guides one in the use of the inertia concept; this is not an operational definition. Students routinely abuse the concept of inertia, treating it as if it were a force or using it as a blanket "explanation" for all manner of mysterious phenomena. “It happens because of inertia”. No doubt you’ve heard that. (Homework: think of all the events you have heard students “explain” using that phrase.)

The term “inertia” should be retired from introductory physics. Let’s give it a nice party, talk about old times and then walk it to the door. Its close cousin, mass, is a fine concept with a respectable pedigree from Newton’s second law. There is, however, an idea that we need to capture, a new chunk to identify. This chunk points to the real meaning for our retired concept of inertia. Given a non-zero net force, it takes time for the velocity of an object to change. The interval of time can sometimes be very small, but it can never be zero. The amount of time is related to the system’s mass (hinting at the second law). I call this the inertia principle out of nostalgia; it could also be called the velocity-change principle. This targets the idea inertia was traditionally meant to explain. It also helps remind students what is actually happening when a collision occurs or an object “suddenly” stops. These processes don’t happen instantly; they require an interval of time. This also helps to remove the apparent differences between continuously acting forces (the constant forces we like to study) and short, impulsive forces which can seem very different or go unnoticed entirely. For the record, my students don’t really remember the phrase “the inertia principle”. But they do say things like, “No, it doesn’t happen instantly. It takes time for the velocity to change.” Compare that with “it happens because of inertia”. Which demonstrates a better understanding? (Homework: try out this principle when you perform the table cloth and dishes trick.)

The second law: cause and effect

After the careful preparation of several days spent on the first law students are primed for the second law. They have a clear idea of the net force and its special connection with acceleration. They also know that mass is the special mediator between force and acceleration, naturally leading to the question of how mass affects the resulting acceleration. I give the second law the nickname of **the law of cause and effect**. This nickname helps prevent students from making errors of reasoning that are mathematically logical but physically bizarre. Consider an equation from math class like $z = xy$. What happens if you double x? Clearly, z doubles as well. Give a student the equation $F_{net} = ma$ and ask what happens if we double the mass in a given situation, they may actually say that the net force will double! Emphasizing the idea of cause and effect helps guide students in the use of these symbols, cuing them to reflect on the physical constraints of the situation rather than the mathematical structure of the law alone. (Homework: think of other equations where students commonly forget the physical constraints and interpret them in a naïve, mathematical way.)

The real excitement of the second law comes from its vector nature. It may be easy to understand that the direction of the acceleration is the direction of the net force (which I drill during the first law). But what if the net force is not parallel to the velocity? Panic! When students meet projectile motion in grade 12 (don't even consider it for grade 11) we need to extract a new chunk from the second law. Students need to explore in a concrete way how the velocity vector changes when the net force is no longer parallel to it. (We use hoverpucks on a wide incline). Nothing about this is obvious or intuitive. (Homework: ask your students unbiased questions about what they think will happen and you will learn interesting things.) This leads us to our next chunk, **the orthogonality principle**: a force in one direction has no effect on the velocity in a perpendicular direction. Another way of saying this is that Newton's first law applies separately to each perpendicular direction.

Soon we reach the very thorny topic of circular motion, which I have treated in the June 2012 OAPT Newsletter. The conceptual foundation for circular motion and all curvilinear motion can be summed up through another chunk, **the speed and direction principle**: a force parallel to the velocity changes only the speed; a force perpendicular to the velocity changes only the direction. Once students are confident that a component of a force still counts as "a force" this principle becomes very powerful.

The third law: force pairs

Consider this typical definition of the third law, courtesy of a ministry approved textbook. (Spoiler alert: I don't like this definition.)

"For every action force there is a simultaneous reaction force that is equal in magnitude and opposite in direction," from Physics 11, Nelson (2011).

If you ask a typical physics student, "What do you think action and reaction mean?" what would he likely say? How would he interpret these terms? Not the way we do, guaranteed! He might come up with ideas like "cause and effect", "first this, then that", or "something moving or impulsive". The choice of language in this definition is very problematic. Including the word "simultaneous" to appease the physics lawyers helps about as much as holding the brakes while hitting the gas.

How about this definition from the other approved physics textbook:

"If object A exerts a force on object B, then B exerts a force on A that is equal in magnitude and opposite in direction," from Physics Source 11, Pearson (2011).

This seems to be an improvement, except that in the following paragraph they go on and on about action and reaction forces! Zounds! In this definition there still is a problem with causality implied by the "if - then" construction. We are still left with the impression that one force happens first and the other happens as a response.

We need some serious redaction on the words "action" and "reaction". They should be banned from discussions of the third law! Outlawed! To better describe the third law we need the concept of interactions, which I described in detail in the last OAPT newsletter (inverse-spoiler). This forms the core of my definition of the third law. So long as we are not considering fields, the third law can be reformulated as:

Newton's Third Law for the 21st Century

Whenever two objects interact they exert forces on one another. The two forces from a single interaction form a **3rd law force pair** and have the following properties:

- they have the same magnitude;
- they point in opposite directions;
- they are the same type (gravitational, normal, etc.);
- they arise and act simultaneously;
- they involve the same pair of objects;

This understanding of interactions is known as Newton's 3rd Law.

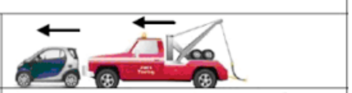
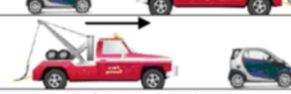
Another feature of my previous article is a tool that helps students think about these interactions and "see" the third law. Imagine a doll resting on a table. The interaction diagram shows the four important interactions that are present in this situation. Each interaction line represents a pair of forces, a third law pair. For example, the line between the doll and table represents the normal force interaction between these two objects and implies a mutual influence of each object on the other.

So you think everything is fine and your students are happy with a new definition of the third law. Then you give them this question as a check:

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.

15. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

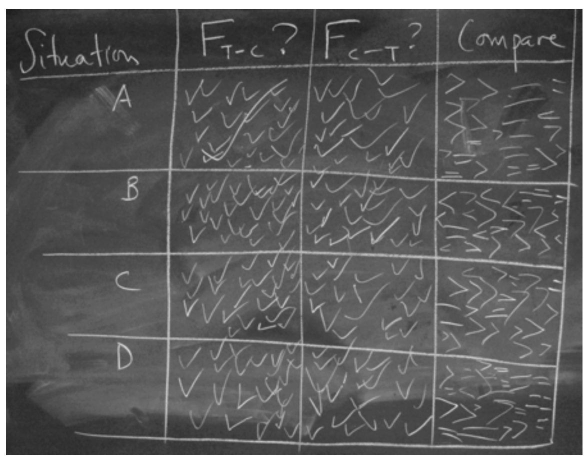
Guess what they answer? By the end of grade 12 after much careful intervention, only 74% of my students choose the correct answer to this question. (Which is?) Students have a very deeply held belief that the third law doesn't apply to situations like this. In grade 11, before we develop the third law, I give my students four situations (illustrated using the Smart car and the tow truck, above) and naively ask them which forces exist (force of car on truck, truck on car) and how their sizes compare. Then they pool their results on the chalkboard. The pooled results from my class of 30 and two individual student results are shown below.

Situation	
a) A truck pushes a stalled car from behind. They move together at a constant velocity.	
b) A fast moving car hits a truck at rest.	
c) A fast truck hits a car at rest.	
d) A truck tows a car. They are speeding up together.	

Exists?		Compare (<, >, =)
$\vec{F}_{T-C}$	$\vec{F}_{C-T}$	
yes	yes	equal
yes	no	>
yes	no	>
yes	yes	equal

Exists?		Compare (<, >, =)
$\vec{F}_{T-C}$	$\vec{F}_{C-T}$	
Yes	Yes	>
No	Yes	<
Yes	No	>
Yes	Yes	=

Notice how for situation C they very strongly favour the truck exerting the larger force. When applying Newton's third law to situations, students are often led astray in the following ways. They think that:



- the "stronger" object exerts a greater force
- the moving object or a faster-moving object exerts a greater force
- the more active or energetic object exerts more force
- the bigger or heavier object exerts more force

This brings us to what I call *the third law conundrum*: if the forces in a third law pair are always same size, why are there such different results for the two objects involved? Three common reasons are the differences in mass of the objects, differences in velocities, or one object experiences other forces. We need to lead students through an examination of these situations to try to help them reinterpret their common sense and personal experiences. When they notice that the Smart Car gets clobbered by the truck, we need to help them understand that they are not observing forces; they are observing the results of forces, meaning the accelerations. Their intuition is not wrong – the smart car does get clobbered. Instead they need to develop new physics ideas and re-examine familiar situations in the new light of their growing understanding.

Law and order: special forces unit

Create a special forces unit for your grade 11 and 12 courses using our reformulated laws. Start your beginning physics students off right. We use the Force Concept Inventory at our school to help track student understanding of acceleration and forces. Our historical average (five semesters) for students beginning grade 12 has been 53.0%. Having made these changes to the grade 11 course, our new grade 12 students this fall have scored 59.8%, making for a statistically significant improvement (two-tailed student t-test = 0.026, n=53, Cohen's d = 0.34). Try this out for yourself and see the difference. Or drop by my class to observe the PERsuasive teaching of forces in action.

We teachers forget what it's like to tackle Newton's laws for the first time. It is challenging and exciting for students when done well. Listen to your students talk about forces and you will hear many of the points I have mentioned in this article. Check out my online resources (**www.meyercreations.com/physics**) to find my complete lessons. Challenge yourself to use these new ideas to help your students improve.

Demo Corner

Illuminating the Inverse Square Law

Joanne O'Meara
Column Editor

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Submissions describing demonstrations will be gladly received by the column editor.

You will need the following materials for this demonstration:

- a flashlight (or similar bright point-like light source)
- some cardboard
- ruler or measuring tape
- light meter app for a smart phone or tablet

Remove the front cover of the flashlight to expose the bulb. Cut a square hole in the cardboard that is approximately 1.5 cm by 1.5 cm and mount the cardboard approximately 2.5 cm from the light bulb. In a dark room, measure the light intensity from the bulb with your app at several (5 or more) distances (r) from the bulb. If you cannot make the room very dark you should do a background measurement (with your flashlight turned off) and subtract this value from your readings at each distance. Your students can record the data as you go and then plot intensity versus r or 1/r2 and describe the resulting curves. This activity could be used in conjunction with the law of universal gravitation, Coulomb's law, optics, nuclear physics, sound, etc., any subject in which the inverse square law plays a role.

Joanne O'Meara is a faculty member in the Department of Physics at the University of Guelph and currently serving as the Associate Chair of the department. She regularly teaches courses at the first, second and fourth year undergraduate levels, and is passionate about teaching and learning physics for all ages.

Getting Involved

Write to Us

Have something to share? Send it to us!

We are always looking for news about what's going on in the physics classrooms of Ontario. You don't have to be a PER or STEM expert to get published in the Newsletter! Send us your classroom anecdotes, physics jokes, project ideas or samples of student work. Send us your comments about the newsletter or about the direction that physics education is taking. We want to hear from you!

Email to **newsletter_editor_8@oapt.ca**