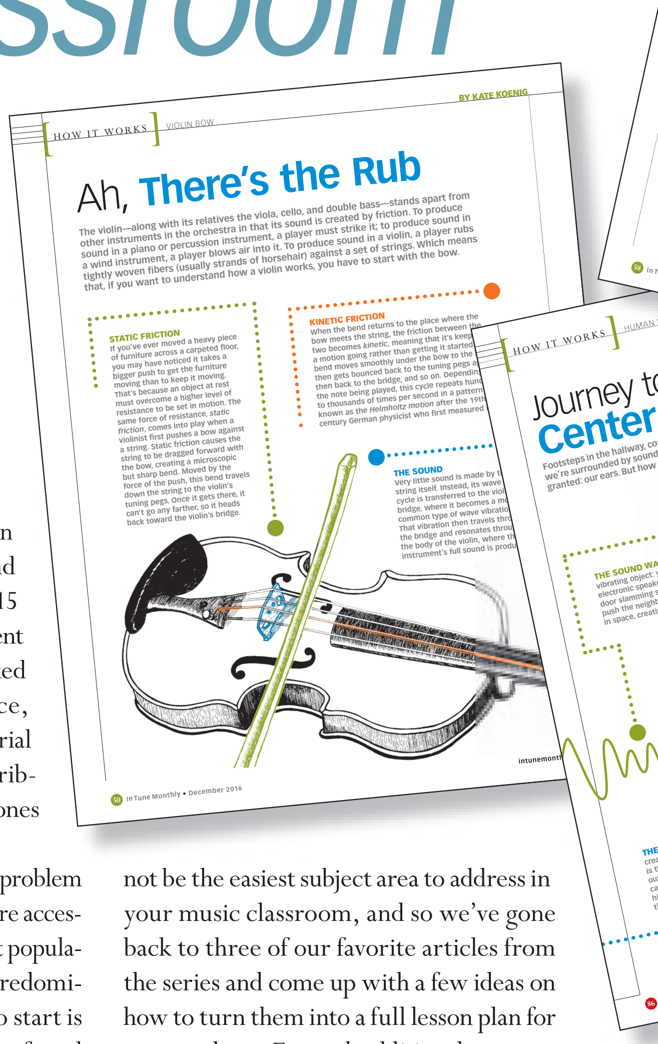
HOW IT WORKS *in the Classroom*

This season, each back page of *In Tune* has examined how music and science intersect. Here are some suggestions for engaging your students further on the subject.

BY KATE KOENIG


HOW IT WORKS | VIOLIN BOW

BY KATE KOENIG

Ah, There's the Rub

The violin—along with its relatives the viola, cello, and double bass—stands apart from other instruments in the orchestra in that its sound is created by friction. To produce sound in a piano or percussion instrument, a player must strike it; to produce sound in a wind instrument, a player blows air into it. To produce sound in a violin, a player rubs tightly woven fibers (usually strands of horsehair) against a set of strings. Which means that, if you want to understand how a violin works, you have to start with the bow.

STATIC FRICTION

If you've ever moved a heavy piece of furniture across a carpeted floor, you may have noticed it takes a bigger push to get the furniture moving than to keep it moving. That's because an object at rest must overcome a higher level of resistance to be set in motion. The same force of resistance, *static friction*, comes into play when a violinist first pushes a bow against a string. Static friction causes the string to be dragged forward with the bow, creating a microscopic but sharp bend. Moved by the force of the push, this bend travels down the string to the violin's tuning pegs. Once it gets there, it can't go any farther, so it heads back toward the violin's bridge.

KINETIC FRICTION

When the bend returns to the place where the bow meets the string, the friction between the two becomes *kinetic*, meaning that it's keep a motion going rather than getting it started bend moves smoothly under the bow to the then gets bounced back to the tuning pegs a then back to the bridge, and so on. Depending the note being played, this cycle repeats hund to thousands of times per second in a pattern known as the *Helmholtz motion* after the 19th century German physicist who first measured

THE SOUND

Very little sound is made by t string itself. Instead, its wave cycle is transferred to the viol bridge, where it becomes a m common type of wave vibratio That vibration then travels thro the bridge and resonates throu the body of the violin, where th instrument's full sound is produ

HOW IT WORKS

Journey to Center

A t some point, anyone who's formally studied music theory has probably heard a teacher or peer attempt to romanticize the mathematics of music: the ratios that govern harmony, the subdivisions of rhythm, the patterns found in compositional structure, and so on. But to many students, there's nothing that could sooner suck the life out of an art form than acknowledging its relationship to math. For them, music is meant to be for organic expression, while science is for organized logic and systems—and the two should be kept separate whenever possible.

Where does this divided way of thinking come from? Educators on both the STEM and liberal-arts sides of the aisle encounter stubborn declarations from students like "I'm not creative" or "I'm not good at math." But especially in the case of STEM subjects, the path from thinking "I'm not good at it" or "I don't like it" to "I can't do it" can be exceedingly short.

Although some of these thoughts come simply from feelings of discouragement in the face of challenge, they're also reinforced by the world around us. The pervasive myth of left-brain vs. right-brain dominance tends to support the notion that intelligence can be constrained by identity rather than being fueled by both an open mind and a willingness to grow. In the 2015 Programme for International Student Assessment (PISA), the U.S. ranked 38th in math and 24th in science, behind many other advanced industrial nations. A number of factors contributed to these results, but cultural ones shouldn't be overlooked.

One possible way to address this problem is to make math and science both more accessible and more appealing to a student population that views itself as strictly or predominantly "left-brain." A good place to start is by illustrating the beauty that can be found in the places where art and science combine. The occurrence of fractals in nature, the language-like code behind visually engaging websites, and the expressive electronics of a guitar amplifier are all great examples. Learning how to embrace the STEM subjects doesn't mean leaving your identity as an artist behind; it actually broadens and strengthens that identity.

Which brings us to *In Tune*'s How It Works series. In these articles, found on the back page of every issue for our 2016-2017 season, we've attempted to bring out the living, breathing beauty in the physics of acoustic instruments. We know this may not be the easiest subject area to address in your music classroom, and so we've gone back to three of our favorite articles from the series and come up with a few ideas on how to turn them into a full lesson plan for your students. For each additional concept, you can explain, discuss, and share related videos or musical performances.

THE SAXOPHONE REED (MARCH 2017 ISSUE)

The physics of generating a sound in a saxophone are common to several other wind instruments in the orchestra. To rehash the lesson from last month's article, there are three principal steps: First, the player draws air into his or her lungs, which creates a buildup of air pressure. Second, the player blows into the instrument, releasing the air. Because of the pressure difference between the player's lungs (high pressure) and the

atmosphere inside the instrument (average pressure), the air flows with considerable energy. Third, the mouthpiece reacts to that air flow in a way that creates a sound wave, which is then amplified by the body of the instrument.

Elaborate on this lesson with the class by comparing it to the flow of electricity. Before entering the saxophone, the air current from a player's lungs acts like a direct electric current—it flows in a straight line. Once the air moves into the mouthpiece, the pressure difference causes the tip of the reed to oscillate. The reed acts as a transducer—something that converts one form of energy to another—and turns the direct current (DC) of the air into an alternating current (AC), otherwise known as the sound wave.

This analogy applies to all brass and reed instruments. For brass instruments, the player's lips take the place of the reed, acting as a valve that rapidly opens and closes, upsetting the direct current of air and converting it to an alternating current vibration.

THE VIOLIN BOW (DECEMBER 2016 ISSUE)

Our lesson on the violin focuses on the phenomenon known as the Helmholtz motion, and compares the forces of static and kinetic friction. As the violinist drags the bow against the string, the static friction between the two objects—or the force present when the bow touches the string, before the two are set in motion—pulls the string forward, creating a microscopic kink. That kink then flows down the string until it hits the bridge, where it bounces back in the opposite direction, in a path that mirrors the original motion. Because it's moving, the kink flows under the bow with the ease of the reduced force of kinetic friction. It repeats this pattern in rapid motion as the string vibrates.

While the Helmholtz motion is a marvel

A saxophone reed works much like a transducer.

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in itself, there are a number of other concepts you can explore with your students. One is what happens post-Helmholtz: The bridge turns the string's vibration into a vibration that can pass through the body of the violin, acting as—you guessed it—a transducer. At that point, the body begins to amplify the sound; the movement between the top plate and the back plate is especially important here, but every piece of wood that goes into the instrument plays a role in its overall tone and resonance. Violin makers like the famous Antonio Stradivari realized this, refining the voice of the instrument without the knowledge of acoustics to which we're privy today, but with dedicated hands and ears alone.

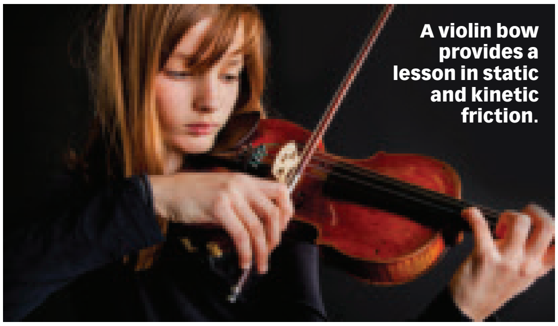
Another captivating aspect of the Helmholtz motion is its creation of a saw wave in the string. If you're unfamiliar with saw waves, their name is derived from their resemblance to the jagged edge of a saw. The saw waves generated by a violin aren't as perfect as those replicated by a synthesizer. However, they stand in contrast to the very imperfect waves generated by nearly every other instrument in the orchestra. In fact, it's the special vibrations of the violin's body that cause this broader range of frequencies to be produced by the instrument.

THE CYMBAL
(FEBRUARY 2017 ISSUE)

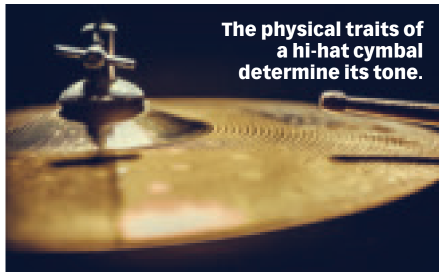
The cymbal is an interesting choice for a physics lesson, because it appears to be a very basic instrument. To a layperson, many cymbals sound pretty much the same: noisy. However, drummers and educated musicians will notice how cymbals of different shapes and sizes have subtly different tones and pitch ranges.

The sound of a cymbal is determined by each one of its physical characteristics, from its diameter and thickness down to the method by which it's made. Hammering a cymbal into shape—as opposed to pressing it or spin-forming it—will cause it to produce higher frequencies.

Illustrate to your students the concept of pitched percussion. It may be news to your non-drummer students that drums can be tuned and that cymbals have variations in tone. Compare a single hi-hat cymbal with a crash and a ride, and point to the differences in their physical traits. You can then explain why a performer might choose to assemble a more elaborate drum kit with a wide variety of cymbals.


A violin bow provides a lesson in static and kinetic friction.

Another fascinating feature of the cymbal is its tessitura: in other words, its full tonal range of frequencies. A cymbal's "pitch" is actually a limited range of frequencies that, depending on where the highest highs and lowest lows fall, can enable it to sound in or out of tune with the instruments around it. Like every other acoustic instrument, a cymbal doesn't produce just one frequency, but a range of harmonic overtones that color its sound. Yet while a guitar or woodwind excites a range of harmonics within one dominant series—producing overtones at a third, a fifth, an octave, and more above a fundamental pitch—a cymbal will excite harmonics in several series at once. (As a side note, our article on the guitar string this month is a good introduction to the concept of harmonics.)


The physical traits of a hi-hat cymbal determine its tone.

WHAT'S LEFT

At the end of the day, your students will go back, enriched by their brief scientific excursions, to studying the performance, history, and theory of music. A primary benefit of lessons like those in the How It Works articles is their interdisciplinary nature, and how they can illustrate the ways in which various fields of study are linked, strengthening students' ability to analyze the world around them. Another benefit is the creative inspiration that can come from being taught how to see an everyday object from an entirely different perspective. With any luck, students will notice that scientific concepts can be surprisingly artistic. T