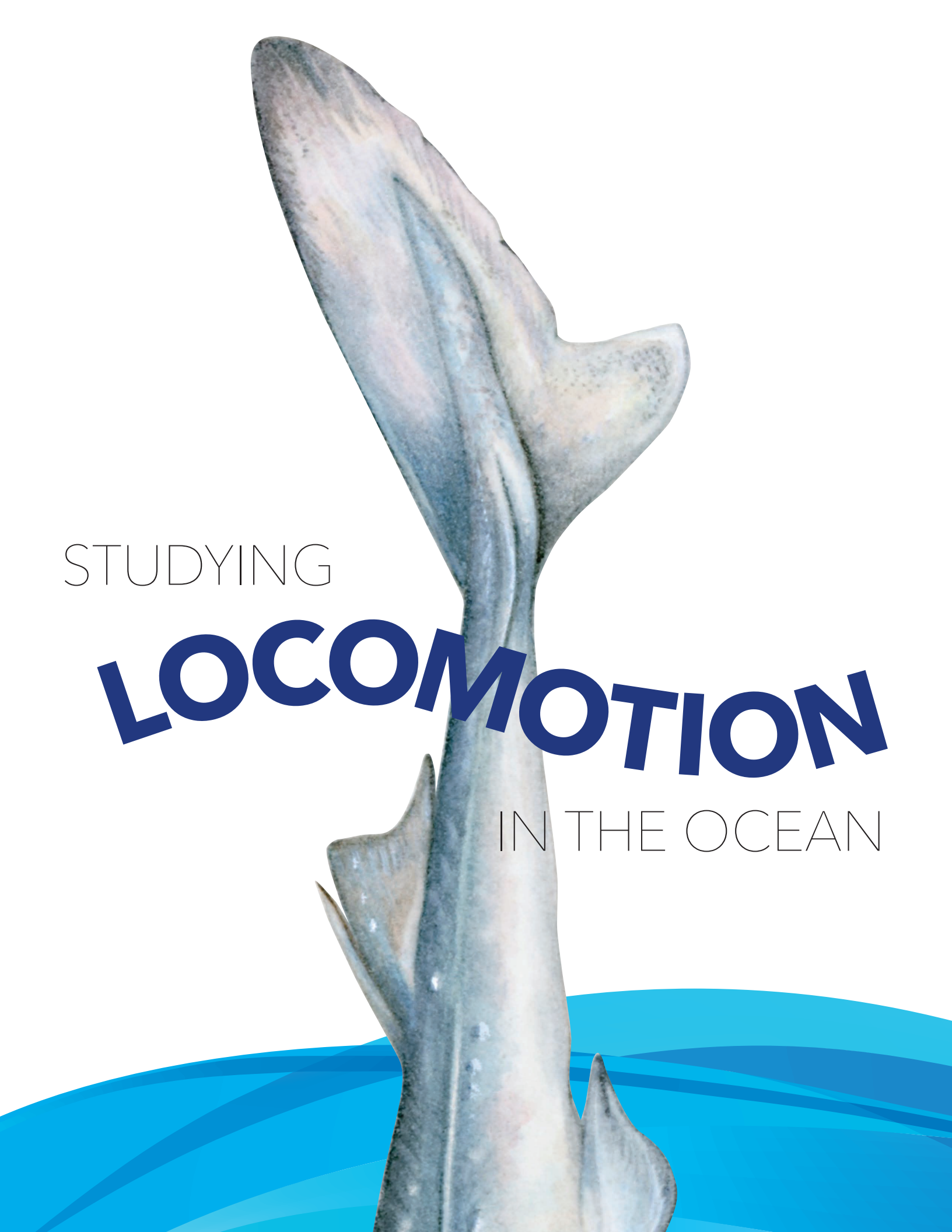
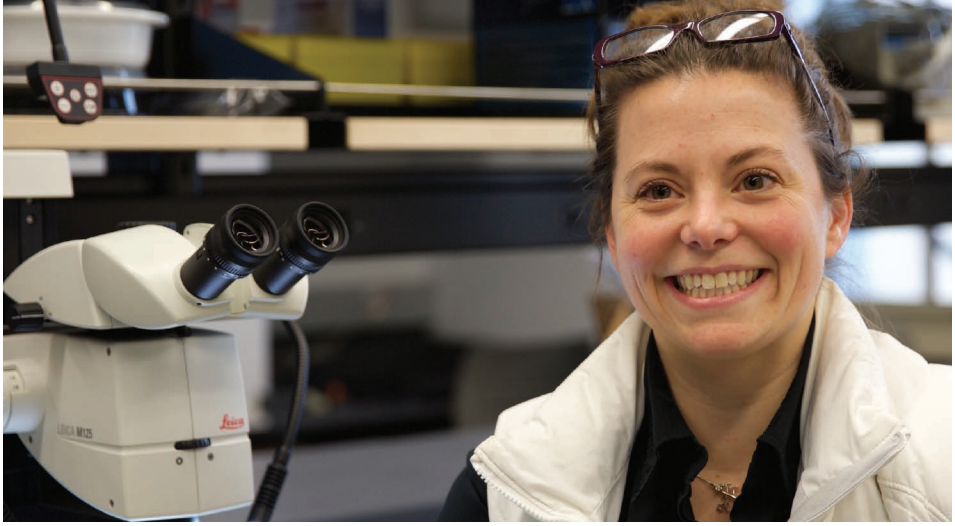

STUDYING
LOCOMOTION
IN THE OCEAN



Assistant Professor Brooke Flammang takes a multidisciplinary look at nature's marine propulsion systems.

Although her lab is located in a very urban setting, in NJIT's Central King Building, Assistant Professor of Biological Sciences Brooke Flammang is embarked on a scientific and technological quest that delves into the world's oceans – and for that matter, potentially every environment inhabited by fish.

Flammang, who came to NJIT in 2014 after a postdoc at Harvard's Museum of Comparative Zoology and Department of Organismal and Evolutionary Biology, is the founding director of the Flammang lab at the university, which focuses on fluid locomotion. With the enthusiastic assistance of a postdoc, NJIT undergrads and graduate students, and STEM-focused high school students, she is taking a multidisciplinary look at nature's marine propulsion systems. The work integrates comparative anatomy and physiology, biomechanics, hydrodynamics, and the use of biologically inspired robotic devices to investigate how organisms interact with their environment and drive the evolutionary selection of morphology and function.

In other words, as Flammang puts it, the lab is dedicated to exploring how fish – and there are more than 35,000 species – "do really cool things, especially with their fins."

"IT'S BIOLOGY PLUS PHYSICS PLUS MATH PLUS ENGINEERING."

– Assistant Professor of Biological Sciences Brooke Flammang

A TREADMILL FOR FISH

Very few researchers have studied fish from this perspective, Flammang says. At NJIT, research in this area is moving ahead with equipment that includes a stationary flume tank in which fish such as the spiny dogfish, a small shark, swim against a current that holds them in place, allowing close examination of fin movement. "Think of it as a treadmill for fish," Flammang explains. This tank was specifically designed for Flammang so that it would be large enough to accommodate these small sharks.

In addition to expanding basic knowledge of how fish propel themselves and the evolutionary imperatives involved, the understanding to be gained can be applied to the propulsion of submersible vehicles. For example, Flammang has conducted research relating the hydrodynamics of flexible-fin fish to the design of a fully autonomous underwater vehicle for the U.S. Navy.

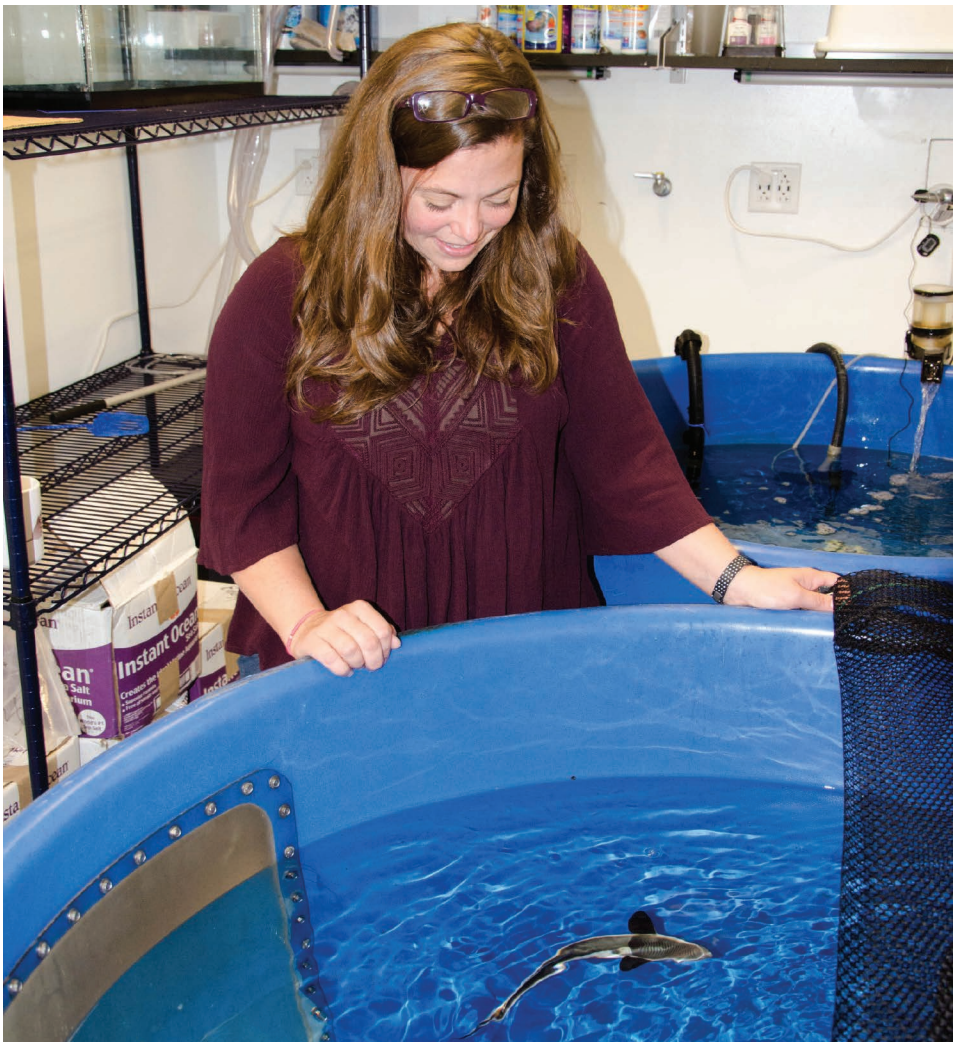
Similarly, her continuing research into the amazing adhesive mechanism of remora fishes, which has yet to be recreated mechanically, could have significant practical applications in biology, medicine and national defense. Using elements of friction, suction and viscoelasticity, as well as a hydraulic differential factor, she is uncovering how remoras can stick fast even to the flexing bodies of whales swimming very fast in drastically changing conditions of temperature and pressure.

ENTICING MYSTERY

While Flammang does not plan to limit her lab's research horizon to a particular species of fish, much of the work she has already done and intends to pursue involves sharks. It's an interest, she admits, that began as a child when she saw the film Jaws. Not only did Jaws spark an interest in sharks, it also helped to start her along the path to becoming a scientist.

"Many of us, perhaps most humans, like to be near the ocean. But we're out of our element in water, and that can be scary. It's a world of enticing mystery.

"We're both fascinated and frightened at times, especially when we think about what could be lurking below the surface that we can't see — like sharks. They have a menacing, 'prehistoric' look that's part of their mystery, and our fascination with them."



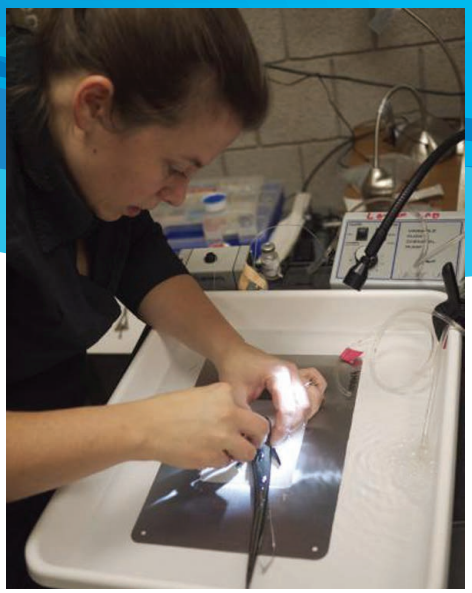
Assistant Professor Brooke Flammang studies the complex biological mechanism that allows the remora fish to cling securely to swift-moving hosts such as sharks and whales and yet release quickly when survival necessitates.

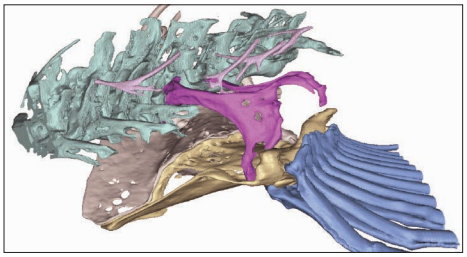
And are shark attacks on humans becoming more common, as some news stories would suggest? Perhaps, Flammang says. Although the chance of a dangerous encounter with a shark remains extremely slight, climate change may be increasing the possibility of contact with humans as sharks follow the creatures, including seals, on which they normally feed into new, wider areas.

A MUSCULAR DISCOVERY

Flammang is widely recognized for her knowledge of sharks in both academia and popular media. In 2014, Scientific American named her "one of the best shark biologists" to follow. It's a hands-on relationship with sharks — and their "structural engineering" — that began to evolve toward her coming to NJIT when she was working on a master's with an emphasis on classical ecology at California State University Moss Landing Marine Laboratories and looking at the egg cases of deep-sea catsharks.

Although Flammang was also studying the reproductive ecology and geographic distribution of catsharks, she became especially interested in the fluid dynamics of the egg cases, which need to be ventilated during the period





Clockwise, from left: Assistant Professor Brooke Flammang sets up equipment at the Fluid Locomotion Laboratory's stationary flume tank; Cryptotora thamicola, a waterfall-climbing cave fish; an anterolateral view of the pelvic girdle of Cryptotora.

before the sharks emerge, typically one to two years. "I realized that I was looking at the egg cases from an engineering perspective, and soon after I came to feel that traditional training in ecology would not take me to where I wanted to be as a researcher."

This conclusion about her direction in science was one of the reasons Flammang subsequently took a summer biomechanics class at the University of Washington Friday Harbor Laboratories, where a standard key assignment was partial dissection of a spiny dogfish — just the head. "I finished the assignment early and, quite frankly, dissected the rest of my shark out of a combination of curiosity and boredom," she relates.

That anatomical exploration led to the discovery of a tail muscle no one had ever seen before. Flammang says, "People had been studying this fish for hundreds of years, so I don't know how the muscle I found could have been missed. But it was."

Further study of the newly discovered muscle in the small shark became the focus of Flammang's work for the balance of the course, and carried over into her initial investigation of locomotion in sharks as a Ph.D. student and postdoc at Harvard University. Now, as a member of the NJIT community, Flammang says that the university offers an environment uniquely supportive of her multidisciplinary research. "Our work in fluid locomotion is an exciting collaboration. It's biology plus physics plus math plus engineering."

FROM FINS TO LIMBS

Recently, Flammang's expertise in investigating how fish do "cool things" with their fins contributed to a very significant finding when she collaborated with Assistant Professor Daphne Soares, a colleague in the Department of Biological Sciences who had been studying a rare species of blind, walking cavefish in the field in Thailand. Their collaboration led to the identification of unique anatomical features in Cryptotora thamicola that enable the fish to walk and climb waterfalls in a manner comparable to tetrapods, or four-footed mammals and amphibians.

The discovery of this capability, not seen in any other living fishes, also has implications for understanding how the anatomy that all species need to walk on land evolved after the transition from finned to limbed appendages in the Devonian period, which began some 420 million years ago. This research was reported in a March 24 Nature Scientific Reports article, "Tetrapod-like pelvic girdle in a walking cavefish," by Flammang, Soares, Julie Markiewicz and Apinun Suvarnaraksha. Flammang and Soares were assisted with the research at NJIT by Markiewicz, an NJIT post-baccalaureate research volunteer in the Flammang lab. Investigator Suvarnaraksha is a member of the faculty of Fisheries Technology and Aquatic Resources of Maejo University in Thailand.

Speaking of the unique anatomical structures seen in Cryptotora thamicola, Flammang says, "It possesses morphological features that have previously only been attributed to tetrapods. The pelvis and vertebral column of this fish allow it to support its body weight against gravity and provide large sites for muscle attachment for walking." With respect to evolutionary significance, she adds, "This research gives us insight into the plasticity of the fish body plan and the convergent morphological features that were seen in the evolution of tetrapods."

CONNECTING WITH WOMEN IN STEM

Beyond the NJIT campus, Flammang is an engaging advocate for greater awareness of science, technology, engineering and mathematics, and for the many STEM career opportunities available to young people. Motivating more young women to pursue STEM careers is particularly important for her.

Flammang's outreach activities include sharing her experiences and achievements in science as a STEM mentor for the Ultimate Mentor Adventure in association with STEM Women on Fire. This online community connects young women with information about STEM education and careers, and with mentors like Flammang. Among the initiative's supporters are the Girl Scouts of America, the National Academy of Sciences and Marvel Comics.

Information, actually the lack of it, is a major factor in attracting women to STEM fields, Flammang says. "If you don't know that someone like yourself is doing interesting science, you feel that it's out of your league, beyond your capabilities.

"On TV, a very high percentage of the people seen doing fascinating work in science continues to be male, even in fields where an equal number of women are doing the same work. That has to change." ■

Author: Dean L. Maskevich is an NJIT Magazine contributing writer.