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Gaining Traction

Kim Hill
Illinois Wesleyan University, iwumag@iwu.edu

GAINING TRACTION

A team that included Gabriel Spalding *(above, left)* and Patrick Dahl '12 has built a functioning acoustic tractor beam by using energy from an ultrasound array. Some of the technology was developed in the IWU physics lab.

Whether collaborating with students on vital research or leading efforts to improve lab instruction nationwide, Professor Gabriel Spalding strives to move physics forward.

Story by KIM HILL

Photos by MARC FEATHERLY

The tractor beam is such a staple of science fiction — from *Star Trek* to *Star Wars* — that it's easy to forget it doesn't really exist. That is, until now.

A team of researchers including IWU Physics Professor Gabriel Spalding and alumnus Patrick Dahl '12 has built a functioning acoustic tractor beam. But rather than pull spaceships toward the Death Star, the IWU team and their collaborators used energy from an ultrasound array to exert force *behind* a centimeter-sized object and pull it toward the energy source.

The discovery — first reported in *Physical Review Letters*, the world's foremost physics journal — was heralded around the globe this spring in dozens of news reports. Of special interest was the technology's potential to develop ultrasound-based techniques for more effective medical procedures such as destroying tumors.

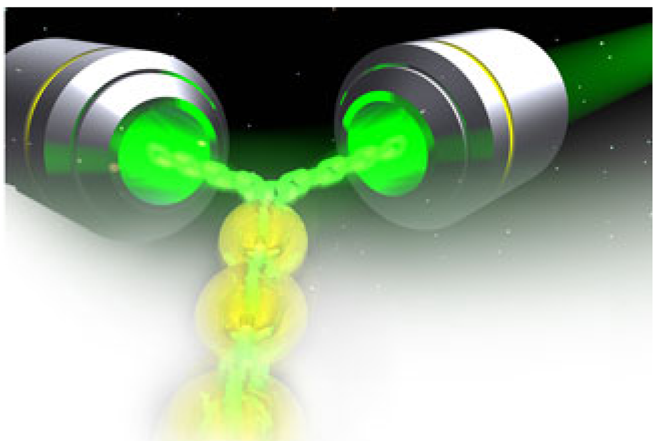
The publicity came amidst a year Spalding describes as "surreal." In a six-month period, he was named a fellow of both the American Physical Society (APS) and SPIE, the international society for optics and photonics, and received high honors from both APS and the American Association of Physics Teachers. Closer to home, he was invested as the first B. Charles and Joyce Eichhorn Ames Professor of Physics at this May's Commencement.

Spalding finds these accolades gratifying. But he says it’s the opportunities they can bring — not just for IWU students, but in his efforts to help improve physics instruction across the country — that are the true reward.

As a Ph.D. student in physics at Harvard University, Spalding focused his research on high-temperature superconductors. He shifted to the field of optical micromanipulation after joining the IWU faculty in 1996. It was, and is, a topic where students could get involved their first semester in college.

Since then, Titans have contributed pioneering research in the field, whether they are building spatial-light moderator optical systems in a University research lab or developing new MRI applications at the largest research hospital in Europe. Those students’ names often appear alongside Spalding’s on his published papers.

“That is the transition that students have to make from high school — that they need to think of themselves as collaborators, that we are in this together,” says Spalding about students who work with professors on research projects at Illinois Wesleyan. “So certainly our students push us, and we push our students, and it’s in a mutually supportive manner.”



This graphic from the University of St. Andrews in Scotland illustrates a tractor beam attracting objects. The magazine *Mental Floss*lauded the discovery with a 2014 Platypus Award.

Patrick Dahl was intending to be a music education major when he enrolled at IWU, but gradually felt the pull of physics, a subject he’d enjoyed in high school. He vividly remembers the first time he labored to set up an optical trap with lasers in Spalding’s lab.

“It didn’t look like it was going to work,” says Dahl. “I had kind of been worn down by the effort, but as soon as we managed to trap a particle I had this big grin on my face.

“There’s euphoria, there’s celebration when things work,” adds Dahl, who spent nearly a year in Europe as a Marie Curie Research Fellow and is now a graduate student at NYU’s Courant Institute of Mathematical Sciences. Spalding adds, “That’s why you put in all the work, and it really is great fun in the end when you see things fit together and you say, ‘Hey, I hadn’t expected this, but, wow, I see it now.’”

Moving from light to sound

To attract students to lab work, Spalding says, "first, I have to get their attention." That's where the *Star Wars* and *Star Trek* references come in. "Some of my collaborators start off a bit skeptical about applying some of these labels," he admits. For Spalding, however, it's just a matter of rephrasing, whether he wants to make physics more accessible to undergraduates, or shine a light on an important scientific discovery by invoking sci-fi lingo.

He points out that holographic arrays that can physically manipulate objects are, essentially, *Star Trek*-style "holodecks" on a micro scale. Terms like "optical tweezers" and "sonic screwdrivers" are also commonly used to describe techniques that use laser beams and ultrasound to move and manipulate very small objects.

Optical tweezers were the subject of a landmark paper that Spalding co-wrote with IWU students Matthew Dearing '00 and Steven Sheets '01 and two University of Chicago physicists. Published in 2001, the paper gave a precise "recipe" on how to design a computer-generated hologram specifically for optical tweezer research. Because of the resulting increase in dexterity at the micro- and nano-meter length scale, the potential applications of optical tweezers — scientific instruments that use a highly focused laser beam to physically hold and move microscopic objects — vastly increased.

Optical-tweezer technology continues to be perfected. Scientists can now sculpt beams of light to target and manipulate individual cells, or their internal organelles, for example. Clinical studies are already underway in Germany to use the technique to sort healthy cells from diseased ones. Recent innovations could also be used to assemble tiny structures or physically manipulate molecules like DNA.

To complement techniques that use light to move and manipulate matter, Spalding began exploring the potential of sound waves to create similar but more powerful beams. In this quest, he joined with collaborators at the Institute for Medical Science & Technology (IMSaT) at Ninewells Hospital in Scotland. With cross-functional teams of scientists, engineers, clinicians and business developers, the institute supports long-term research while applying new discoveries to current clinical and patient needs. Spalding has spent several summers at IMSaT, often accompanied by IWU students.

From the earliest days, much of the institute's work has focused on minimally invasive surgical techniques. "Our team is a mix of engineers and surgeons," Spalding explains. As a physicist, he says he's "the oddball in the group."

The team's experiments proved that, at similar power levels, sound waves *can* move much larger objects than light waves. Using a commercial ultrasound-surgery machine, the team manipulated a four-inch-long triangular prism made of metal and rubber, successfully pulling the target toward the source of the acoustic beam.

Spalding was among the faculty who organized and instructed "IWU Young Scientists," a camp for students entering sixth through eighth grades. The camp is partly funded by the Donnocker Innovation Fund, which underwrites faculty and staff initiatives.

Spalding says the research benefitted from IMSaT's use of near lifelike cadavers, which retain the body's natural look and feel. "These cadavers are ideal for testing the new technologies."

The immediate application of the new tractor beam technology is medical. One goal is to improve ultrasound surgery used to treat and destroy tumors more effectively and efficiently. Down the road, the technology could be used to treat Parkinson's disease and chronic pain.

"If we can encapsulate a drug in a bubble and push the drug to the exact area we want to treat, then it will be more effective and cause less adverse effects on bodies," Christine Demore, a researcher with IMSaT and co-lead author with Dahl of the acoustic tractor beam paper, told the *Edinburgh Evening News* earlier this year. And using the technique to deliver a safe supply of universal donor blood is not science fiction, according to Spalding.

He believes some of the applications are probably a decade away from availability to the public. "However, I really feel that we could provide treatments *today* that would be better than what is currently being provided, both when compared to traditional surgery and when compared to long-term effects from radiation therapies."

While intrigued with these possibilities, Spalding's primary focus will remain basic research. "If you think of research as the tree of knowledge, basic research is the trunk, and applications are a big branch. We hope to have a bigger impact at the trunk by establishing fundamental paradigms, and leave the rest of the tree to others."

Back to basics

Inside Illinois Wesleyan's Center for Natural Science, a sign at the entrance to the physics department reads, "So you want to do research? What's stopping you?"

Like other professors in his department, Spalding believes the only major qualification a student needs to work in the lab is his or her interest. “It is the message we were trying to give to our students from very early on,” he says.

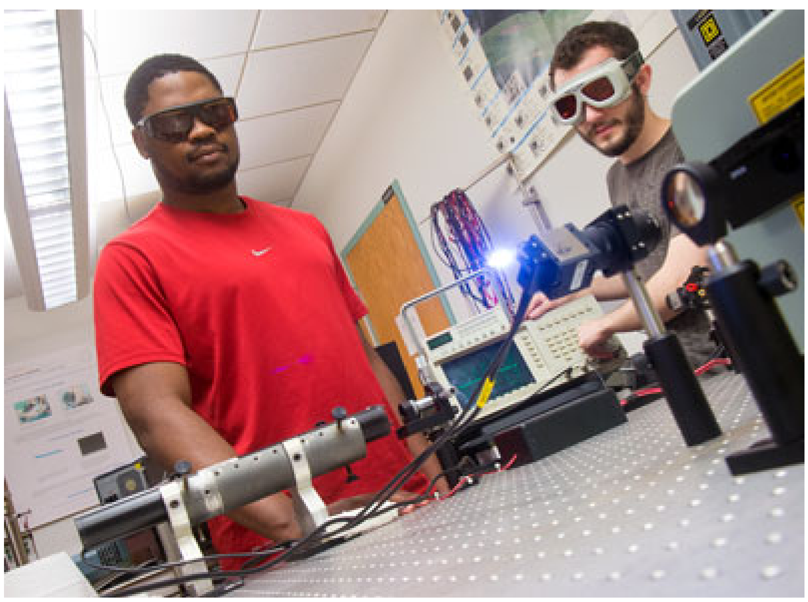
It’s a very different message at some larger research universities, where student–faculty collaboration on research is often confined to the graduate level. Spalding recalls his own frustration with that reality as an undergraduate at Washington University in St. Louis. When he was given the chance to mentor college-level physics students while in graduate school at Harvard, he found he loved the experience.

“The undergraduates were joyful,” he says. “They were exploring science just for the kicks and grins. For me, it was an easy choice to make regarding the kind of place where I wanted to be, which was somewhere I could make a difference.”

It’s in the laboratory where that difference is most notable. “The physics curriculum at Illinois Wesleyan is as much a hands-on, experiment-based investigation as it is a theoretical discipline,” according to the department’s web page.

In the 399-level course, “Experimental Physics,” students have a chance to experience what Spalding describes as “a complete immersion experience” in lab research.

“In this class, students are asked to start from scratch,” says Yongkang Le, a physics professor at Fundan University in Shanghai, who Spalding invited to serve as a visiting faculty member for this course in May.



Seniors Fred Williams (left) and Alex Scherer break down air molecules with a laser during the “Experimental Physics” course this past May Term.

“Experimental Physics” students are given very basic components in which to fabricate sophisticated apparatuses. It’s a very different approach, Yongkang says, than in China, where physics students are given a “recipe from a cookbook” approach, following specific steps that lead to an already determined final product. Less closely guided, the IWU students he observed “make mistakes at the very beginning, but they begin to understand each step in the process. This is much closer to the way a graduate student is doing research," says Yongkang.

Spalding's belief in the power of this kind of hands-on research has led him on a mission to transform undergraduate physics education across the country. In 2007, Spalding co-founded the Advanced Laboratory Physics Association (ALPhA). Comprised of higher education faculty and staff dedicated to experimental physics instruction, ALPhA organizes workshops and conferences across the country to teach other faculty to lead more, or more fully realized, experiments in the lab.

The need for such an organization became clear to Spalding and his colleagues after surveying other institutions and discovering many undergraduate programs nationwide offered relatively sparse lab instruction after the first year. "We found, too, that there was a great deal of stagnation in what was offered," he adds. "People were teaching the same things they could have taught 50 years ago. Physics is a high-tech field, just like electrical engineering, for example, where you can't really justify that sort of stagnation."

As ALPhA's first president, Spalding also initiated a project that makes single-photon detectors available for instructional labs across the nation. Research indicated the high cost of single-photon detectors was often prohibitive in collegiate labs. Spalding coordinated an effort to provide less expensive detectors sufficient for undergraduate experiments. In the past five years, Spalding has personally shipped 300 single-photon detectors to institutions across the country, including Yale and the University of California at Berkeley.

"The single-photon initiative is drastically changing what people are able to do in teaching quantum mechanics," says Spalding.

"If you look at the textbooks before this, they're highly mathematical tomes that don't really mention experiment. Now, there are new texts reflecting this new initiative on experiments — and we've been a big part of that. It's very exciting."

Spalding (center) was invested as the University's first B. Charles and Joyce Eichhorn Ames Professor at Commencement in May. The greatest benefit of endowed positions, says Spalding, "is that they enhance the opportunities we provide to our students in ways that will transform their lives." Through the just-concluded *Transforming Lives* campaign, the number of endowed faculty positions at IWU increased to more than 30.

According to IWU Provost Jonathan Green, any university wanting to improve its undergraduate physics curriculum should take a look at Illinois Wesleyan. “Our physics department has developed an unrivaled educational opportunity for our undergraduate students, combining strong theoretical foundations with an integrated and intensive laboratory sequence throughout the curriculum. Our students enjoy a hands-on experience in physics rarely encountered outside of graduate school, which is one of the reasons our students are so desirable to the very best graduate programs.”

Among the recent recognition Spalding received was APS’s inaugural Jonathan Reichert and Barbara Wolff-Reichert Award for Excellence in Advanced Laboratory Instruction, given for his efforts to expand laboratory instruction nationwide. The APS represents over 50,000 members, including physicists in academia, national laboratories and industry in the U.S. and throughout the world.

“The entire IWU Physics Department could have been recognized by the award,” says Spalding, “because it’s really everybody in the department who has contributed to building something very significant when you compare our program to others.”

“I do hope these kinds of awards raise the profile of the issues we are trying to address,” he adds. “The critical mass of instructional labs at Illinois Wesleyan is a springboard for our students to move beyond the classroom. The skills they develop allow them to ask their own research questions and establish the structure needed to answer those questions.”

Or, as Spalding writes in his “Experimental Physics” syllabus, “You will be expected to develop your own physical intuition, to flesh out and to check out the ideas that you put forth. … Experience shows that you will find your own abilities growing as you struggle to make nature reveal its secrets.”

To read about one physics student's journey, click here.