Embracing the Complexity of Systems

SEAS researchers are bringing an engineering approach to system biology efforts

A Department for the 21st Century

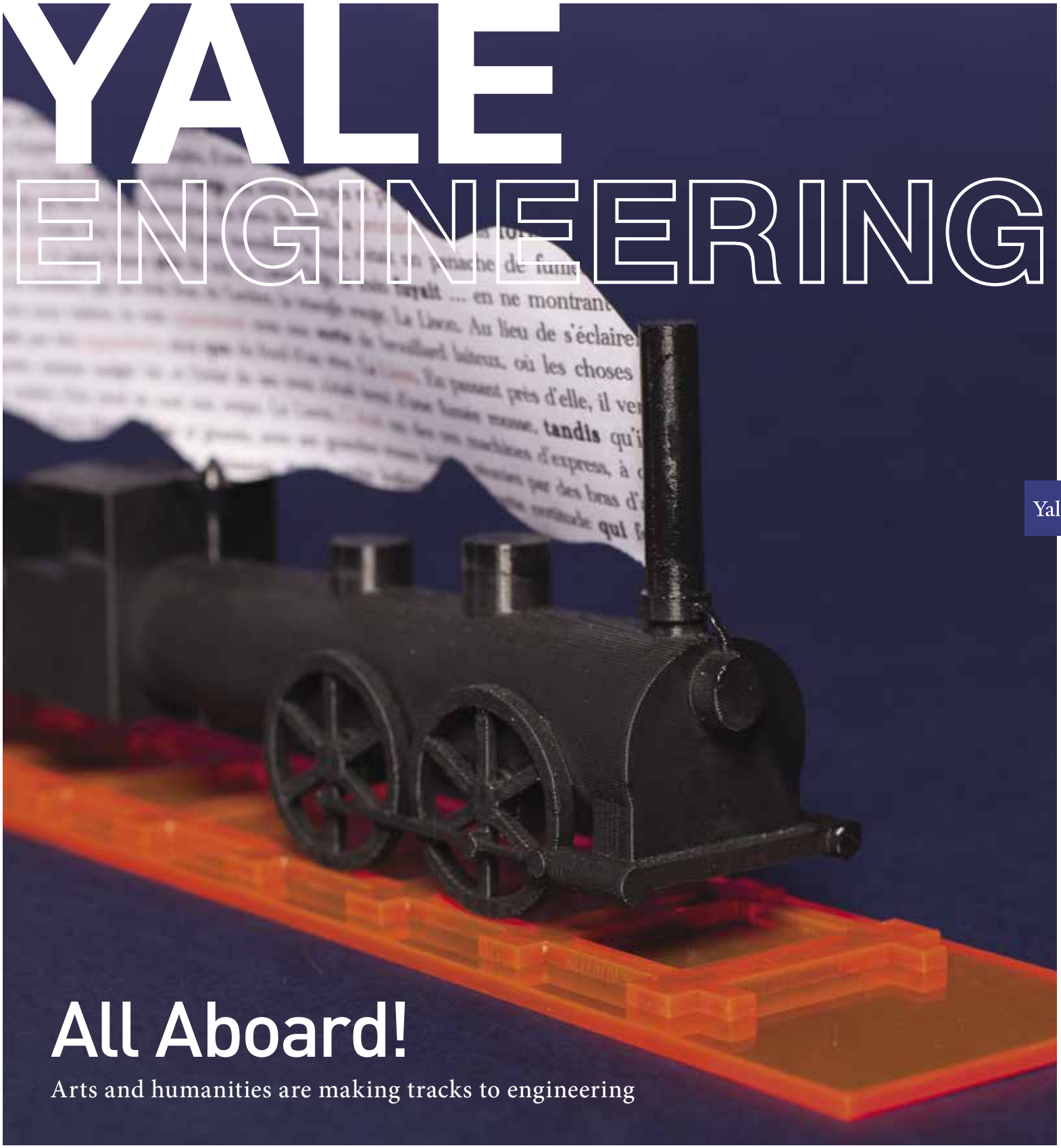
By joining forces with SEAS, Computer Science at Yale has a wider reach than ever

A Hard Look at Soft Matter

Exploring the promises of these mysterious materials

2015-2016

YALE ENGINEERING



Yale

All Aboard!

Arts and humanities are making tracks to engineering

The Publication of Yale's School of Engineering & Applied Science

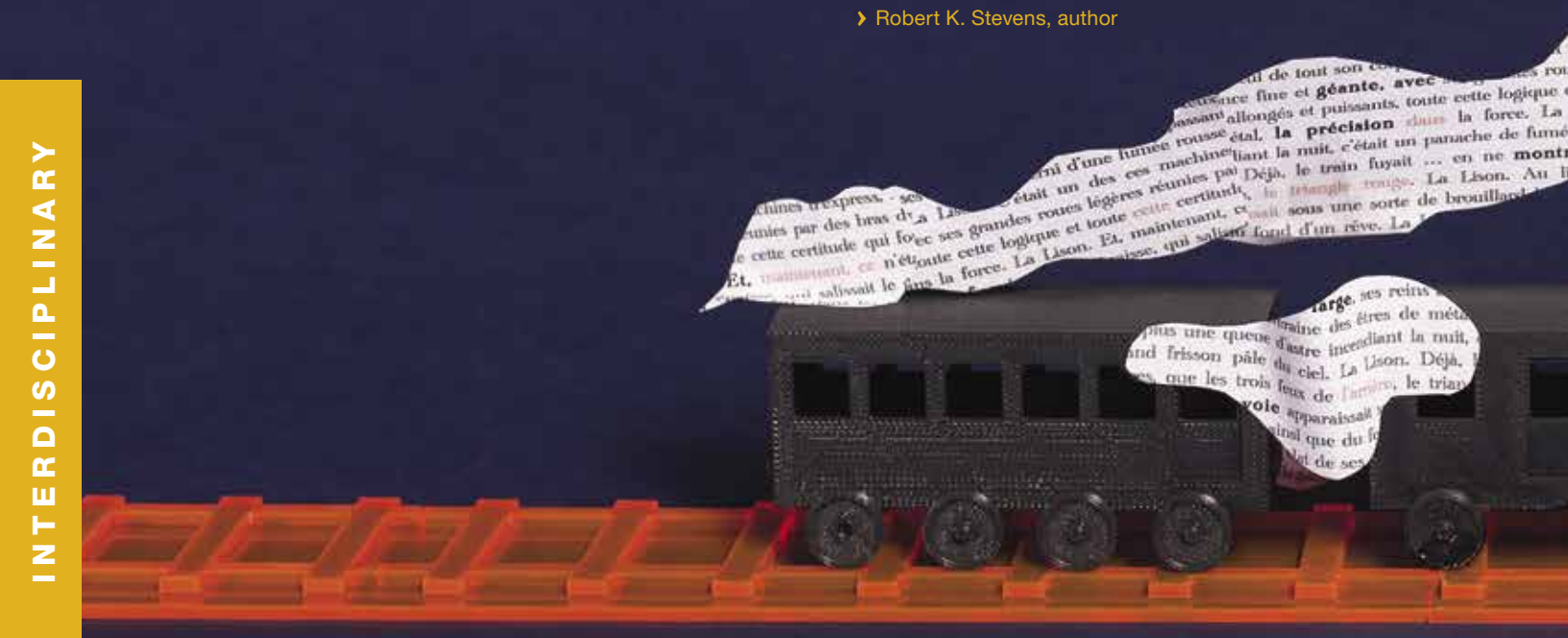
Engineering Connecting to the Arts

From 19th century novels to computers that make their own music, SEAS researchers enjoy the art of engineering

Yale

"Art without engineering is dreaming.
Engineering without art is calculating."

› Robert K. Stevens, author



INTERDISCIPLINARY

Consider for a moment Leonardo da Vinci, painter and prolific inventor — or Steve Jobs, whose computers shaped a generation's sense of design. Popular opinion has drawn an imaginary line between engineering and the arts, but really, the two have long enjoyed a fruitful partnership.

The connection between engineering and the arts at Yale is particularly strong. Composers, museum conservators and illustrators have all worked on recent SEAS projects, ranging from the improbable to the quirky to the futuristic. All can be described as "uniquely Yale" — innovative, ambitious and cooperative.

There's even a place for 19th century French literature. Assistant professor of French Morgane Cadieu noticed that Emile Zola filled his 1890 novel *"La Bête humaine"* ("The Beast Within") with technical minutiae of a prominently featured train — her students have even remarked that it's really a book for engineers. She wondered: What do all these details amount to, really? "Zola's novel is a landmark of realism and naturalism," she said. "Yet, when you follow the descriptions of the machine closely, you realize that they are often evasive and metaphorical."

Could an actual train be built, relying only on Zola's descriptions? To find out, she turned to Yale's Center for Engineering Innovation & Design (CEID). There, the process of translation took many forms. "We first had to translate the original French descriptions into literary English, then translate the literary words into more technical, precise terms of engineering," Cadieu said. "Finally, we translated those terms into an object, into computer code."

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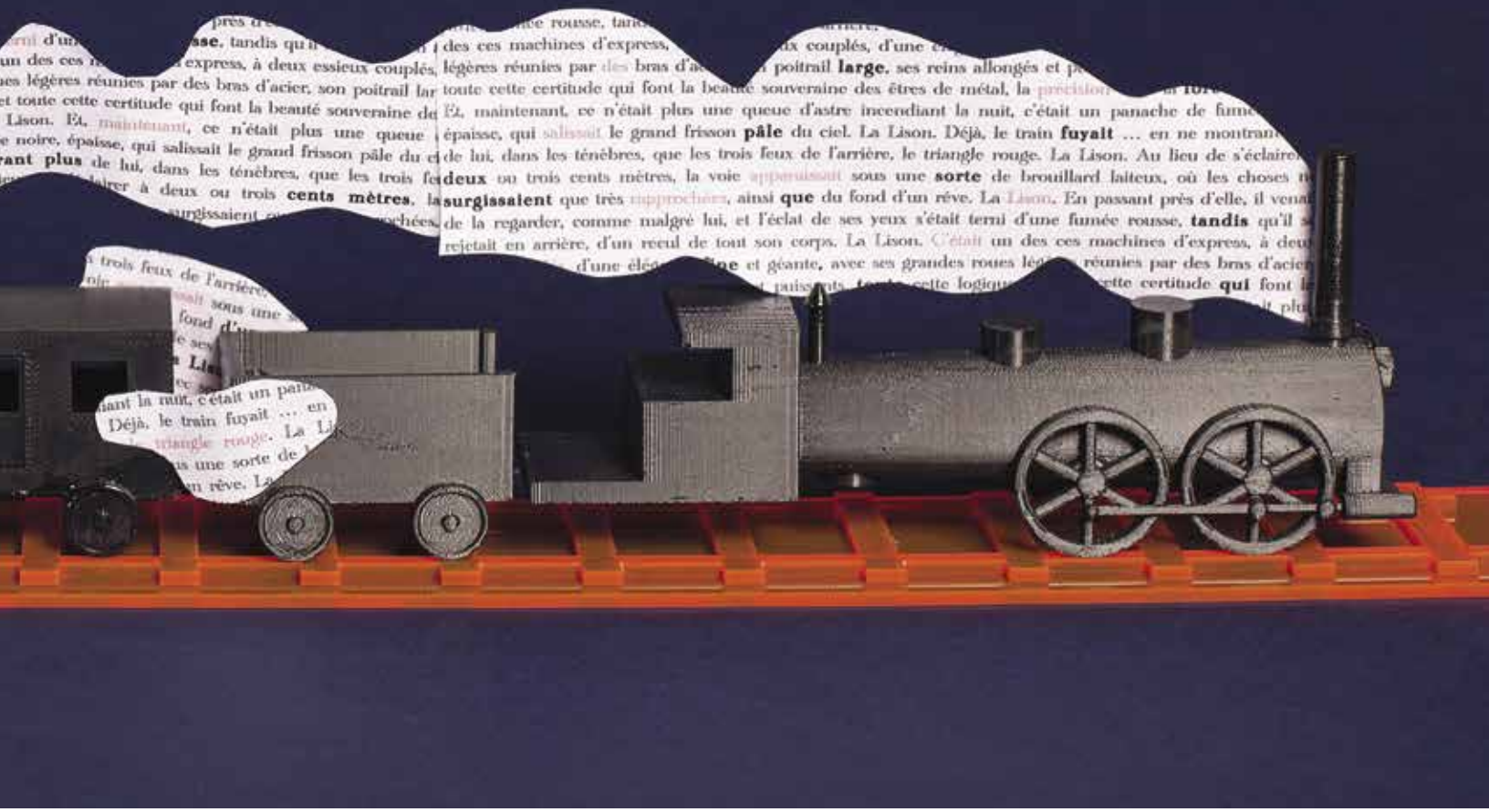
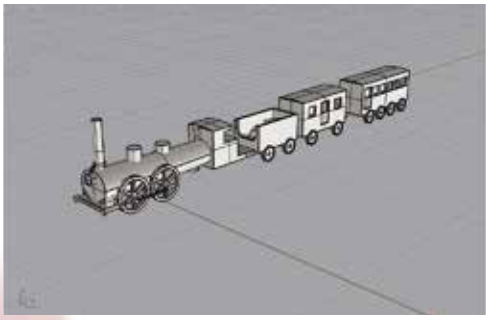
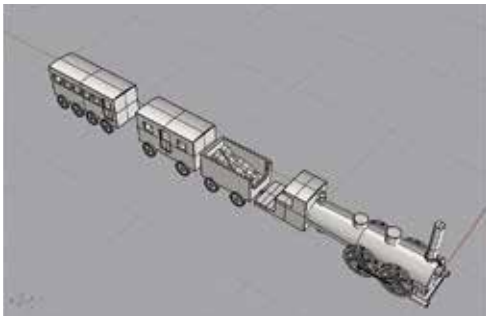






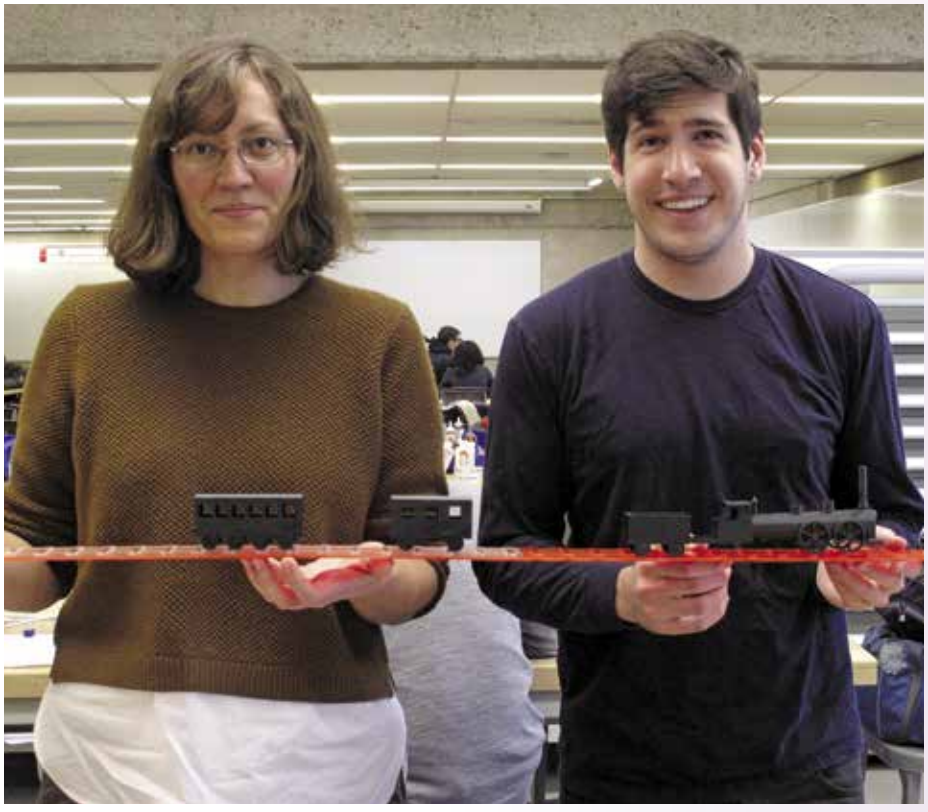
All this translation led to a computer-aided design, which then took physical form by way of one of the CEID's 3D printers. Cadieu's student research team — Sienna Jun '16, John Sununu '15, and Alexandro Gonzalez-Calvillo '16 — worked with the CEID staff, including research support specialist Glenn Weston-Murphy and CEID design fellow Ngoc Doan '14.

The project wasn't entirely literal. Some parts were built to exaggerated proportions in deference to their symbolic importance. The whistle's prominence, for instance, represented the increasing anxiety of Zola's characters. And there was the surrealist touch of a paper smoke trail hovering over the train, bearing literary descriptions.

For the most part, though, the train was made as Zola described it, revealing some serious technical shortcomings. Zola proves himself a master of emotional nuance in this story of murder and betrayal. But designing a functioning train? Not so much. For one, Zola never mentions the train's back wheels. In keeping with the project's guidelines, no wheels were made, but the CEID staff kept the train upright with a nearly invisible hitch near the back of the engine.

And engineering know-how also helped bring a deeper understanding to a classic text. "The project gave me a new appreciation of Zola's work and poetic interpretation of technology," Cadieu said.

Top: *CAD images of Zola's train.* Bottom: *Morgane Cadieu, assistant professor of French, and John Sununu '15 with the 3D model printed in the John Klingenstein '50 Design Lab.*



Making Art from Light

The mechanics of light and screen space are often taken for granted in contemporary art. Screen Space, a course taught last fall by Sarah Oppenheimer of Yale's School of Art and Joseph Zinter, associate research scientist and lecturer of mechanical engineering & materials science, served as a corrective.

The course explored the role of screens and projectors in creative works, and their evolution in the 20th century. "We were thinking about different ways of using light as an artistic medium, but in the context of mechanics and machines," said Zinter who also serves as associate director of the CEID.

For the final project, students designed and built a projection machine that explored the aesthetic language of light, color, and motion. For one project, a student set up red and blue light sources and used a neck massager to animate a mannequin head inside a black box. A set of lenses, acting as camera obscuras, lined the box sides. "So you saw the head moving 360 degrees around you," Oppenheimer said.

For Oppenheimer, whose own work blurs the boundaries between architecture and sculpture, the course explored differences in how engineers and artists approach their work.

"On one hand, in engineering, the test is whether you are able to have the project meet the criteria you set out for it," she said. "In the case of an art project, failure is often the most interesting part of the work. I think it really changed how the engineering students thought about the success of their projects and how the art students thought about their success."

Screen Space explores how the dynamic architecture of screen and projector can be understood as a site of creative work. Students were tasked with creating a projection machine as their final project.

Zinter said the course drew some inspiration from Thomas Wilfred, an artist who used light as his medium. Although his star has faded significantly since, Wilfred's status was once equal to those of Mark Rothko, Jackson Pollack and other contemporaries. You can see Wilfred's work next year, when the Yale University Art Gallery holds a retrospective of his work. Zinter, again bridging the worlds of engineering and art, serves as a consultant.

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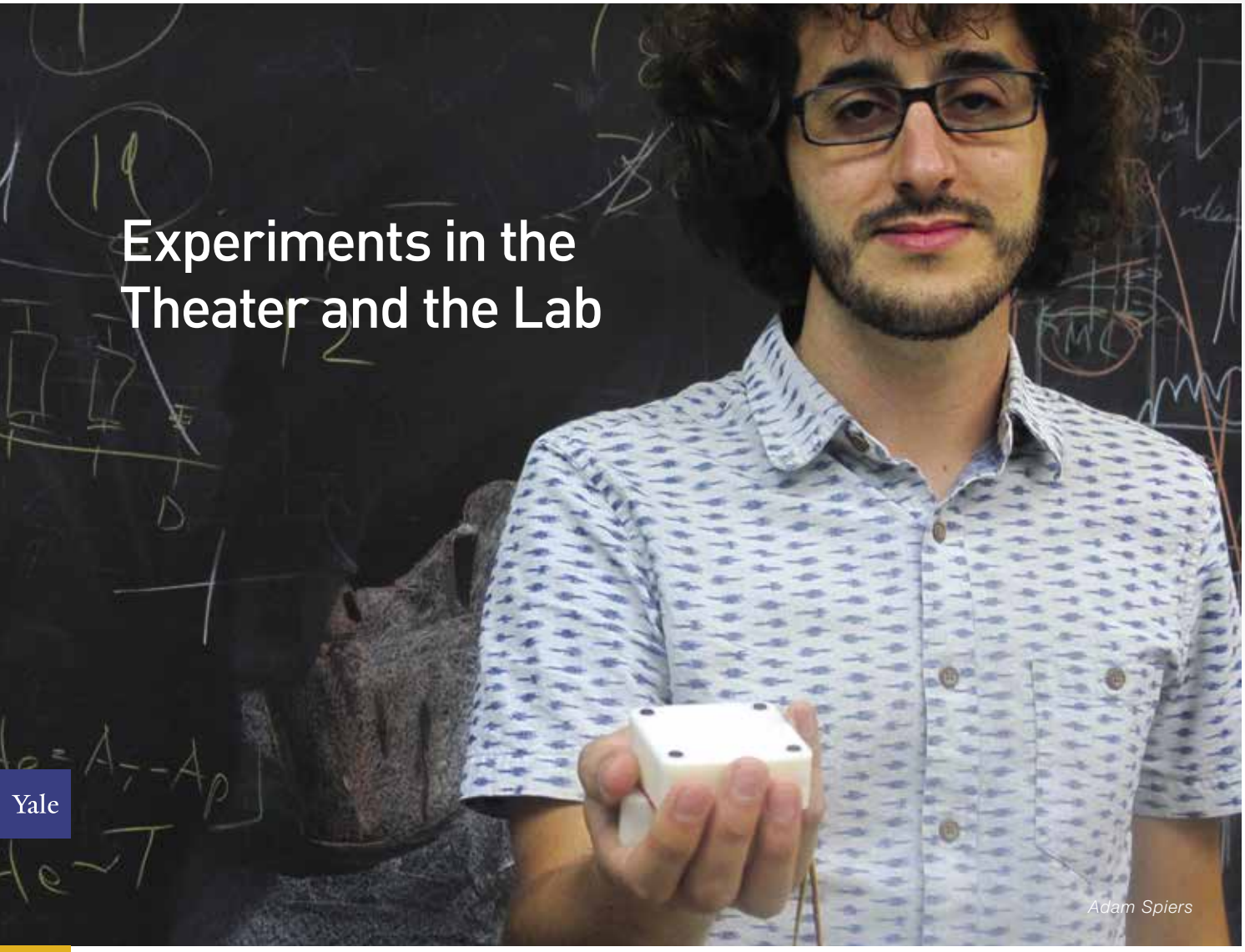
Experiments in the Theater and the Lab

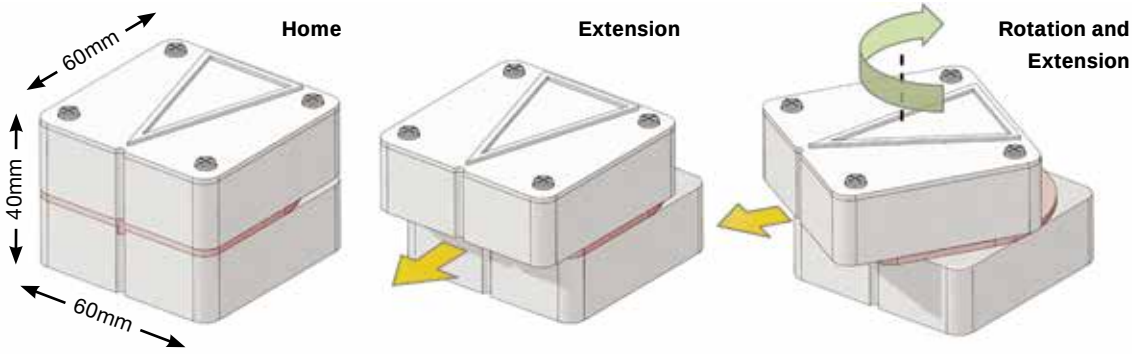

Adam Spiers

INTERDISCIPLINARY

The recent and unlikely merger of mechanical engineering and avant-garde theater helped bring a classic science fiction story to life, and could help the visually impaired navigate their routes.

Adam Spiers, a postdoctoral associate in the robotics lab of Prof. Aaron Dollar, played a critical role in "Flatland," an interactive theater production of Edwin A. Abbott's 1884 story of a two-dimensional world.

Spiers, a haptics specialist, used a 3D printer to build a navigational device that guided audience members through the theater space — an old London church kept in complete darkness. The top half of the handheld, shape-shifting device — dubbed the Animotus — twists to direct the user where to turn and extends forward to indicate the distance to reach it. Spoken narrative and sound effects told the story.



The Animotus guides users by changing its shape, returning to a cube when users arrive at their destination.

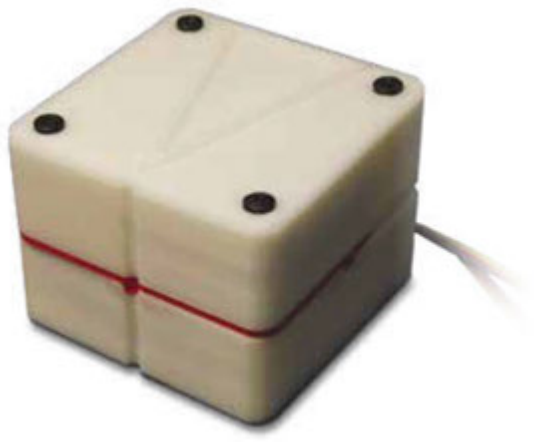
Participants in the interactive production of Flatland make their way through the theater with the help of the Animotus.

Maria Oshodi, artistic director of Extant, the London-based company that produced "Flatland," said the project merged the engineering and arts worlds perfectly. "Both strands needed disciplined testing, evaluating and re-working at many stages," she said.

Spiers said work on the Animotus was "kind of a two-faced project" that produced some interesting results from both the lab and the theater. Data showed that users moved quicker than expected, indicating their confidence in the Animotus. And surveys revealed that they developed a real bond with the device. "It's about 40 minutes that they're in there with the Animotus, so they got pretty emotionally attached to it."

Building the device took some trial and error. "First, we came up with this crazy thing," he said, holding up what looks like a Whiffle Ball inside plastic flower petals. "I collaborated with an artist. He was a puppeteer and we made this cool-looking flower thing." But cool-looking doesn't always translate to functional. When Spiers got his job at Yale, Dollar told him to bring the project. That's where he developed the cube-shaped device that it is now.

"I got to use all these awesome 3D printers, laser cutters, and various engineers' knowledge," he said.



Preservation

Clearing the View

With ingenious new computer programs and the science of gecko feet (we'll explain), SEAS researchers are also helping to preserve art and increase access to it.

Micrometric and sub-micrometric contaminant particles — what most of us call "dust" — have long plagued art conservators. It robs the vitality of a painting's colors and dulls the surfaces of sculptures. The lab of SEAS Dean Kyle Vanderlick, which focuses on thin films and surface properties, recently took on the dust problem. It turns out that there's a lot in art conservation to engage researchers in her field.

"Paint cracking — that's a thin film problem," she said. "How stone falls apart, how monuments fall apart — you're talking about water in a porous environment. That's something at the nanometer level. So there's a lot of interesting thin film, surface, and interfacial physics associated with the preservation of art."

And with the recently established art conservation labs at the Institute for the Preservation of Cultural Heritage (IPCH) at Yale's West

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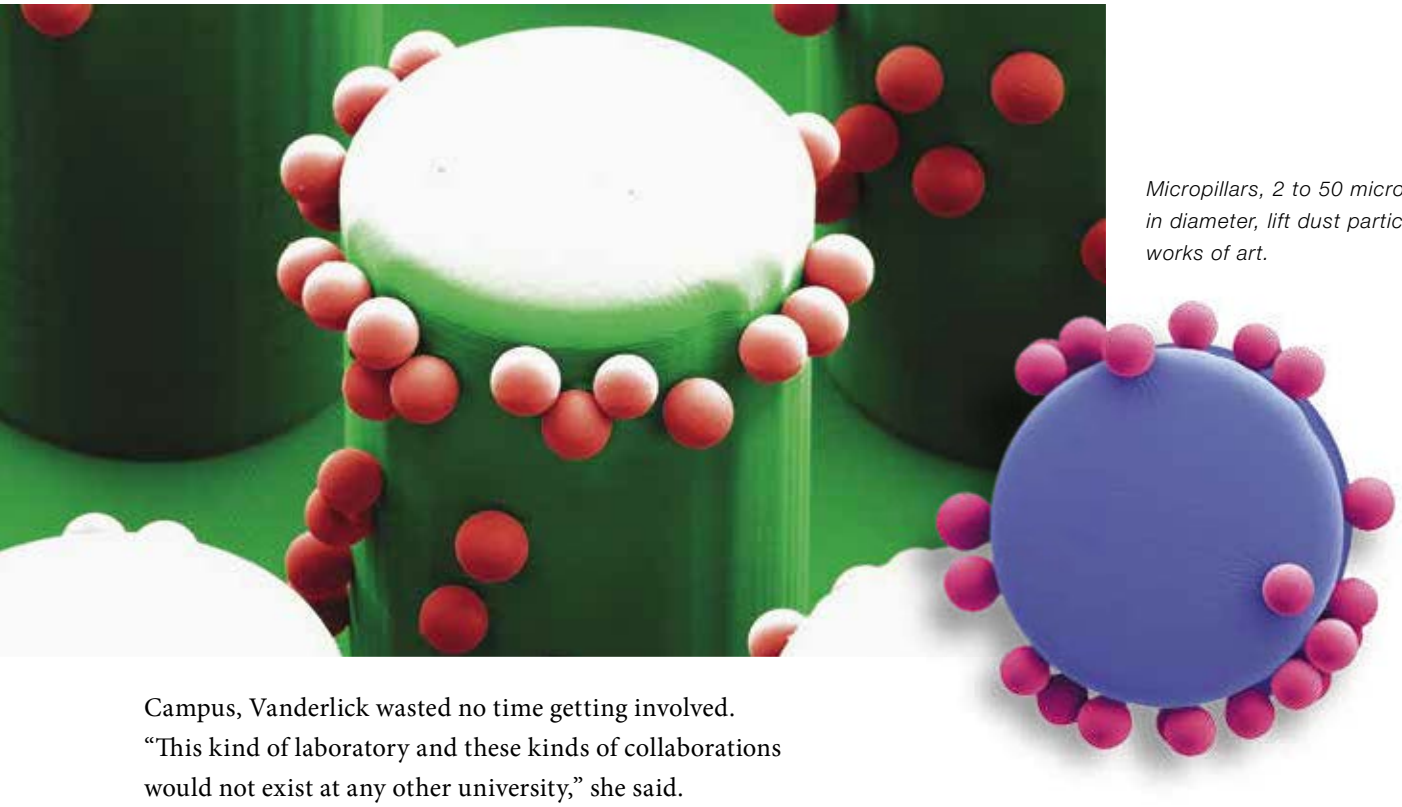


Micropillars, 2 to 50 micrometers in diameter, lift dust particles off works of art.

Campus, Vanderlick wasted no time getting involved. "This kind of laboratory and these kinds of collaborations would not exist at any other university," she said.

Hadi Izadi, a postdoctoral associate in Vanderlick's lab, is working with researchers at the IPCH and workers at Yale's two art museums and the Peabody Museum of Natural History. The dust cleaning method he's devised combines microscopic fibrils and the forces that make static cling. In the lab, he holds up what looks like an ordinary plastic sheet. It's actually an elastic and non-sticky polymer, polydimethylsiloxane (PDMS). Under a microscope, you can see millions of tiny columns. Depending on the size of dust particles you're removing, the pillars range from 2 to 50 micrometers in diameter — bigger particles require bigger pillars.

Izadi knows of fibrillar structures and micropillars. His previous research explored the mystery of how geckos stick to walls. A lot of it has to do with electrostatic charges and the microscopic pillars on the pads on their feet. Applying some of this science to cleaning microparticles made sense, Izadi said. "When you're talking about dust, you're talking about electrostatic charges."

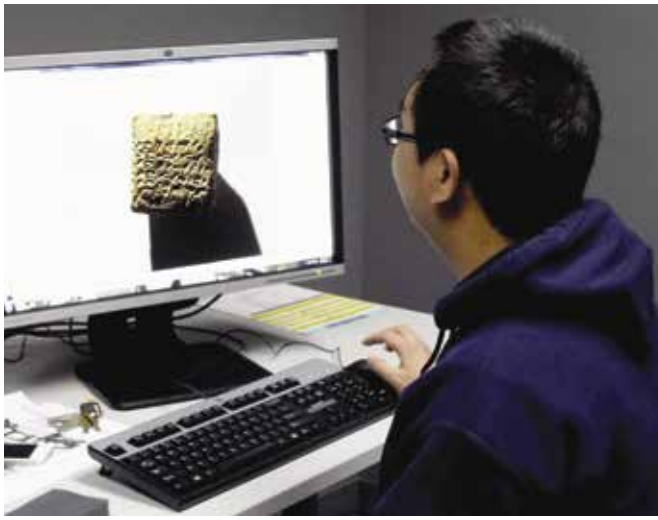
The PDMS polymer has minimal interaction with the substrate — whether it's a painting or a sculpture — but it produces enough electrostatic charge to detach the dust particles. "When it absorbs the particles, they go around the pillars," he said.

Once you match up a sheet with the appropriately sized pillars, the method of cleaning is simply a matter of tapping it to the surface. Tests on various surfaces in his lab have shown total cleaning of silica dust particles and no damage to the surface.

Thanks to a collaboration of the Computer Science Department, the IPCH and Sterling Library, researchers can now call up on their computers a cookbook tablet thousands of years old and examine it from every direction and in all kinds of light.

Starting in 2014, Holly Rushmeier, professor of computer science, helped digitize images of 14 of the Yale Babylonian Collection's "greatest hits." Besides the

Custom-built dome for Reflectance Transformation Imaging (RTI) features 45 lamps from different heights and angles.



Researchers can now remotely study priceless artifacts in great detail, such as these items from the Yale Babylonian Collection.

cookbook, that includes the epic of Gilgamesh, a marriage contract and the first evidence of a contract killing. Each object was placed under a custom-built dome used for reflectance transformation imaging (RTI). The dome is equipped with an overhead camera and dozens of lamps placed at different heights. The result is an image that can be examined under light from 45 different angles.

"Making out some of these characters would be difficult if you only had a static light source," said Chelsea Graham, digital imaging specialist at the IPCH, pointing to the tablet on a computer screen. "Now, you can move the light source and say 'OK, this angle helps me see that it says "one cow" instead of "one goat,'" or something like that. This was neat because we did it with a collection that had never been part of such a high-tech project before."

And to capture the surface geometry of the objects, the researchers used high-resolution 3D laser scanners to produce digital 3D images.

"It's one way to improve access to these treasures at Yale internationally and very much in accordance with the institute's aim of open access," said IPCH Director Stefan Simon. He added that the project was made possible with the assistance of Benjamin Foster, professor of assyriology and curator of the collection; and Eckart Frahm, another Yale assyriologist. Alberto Urcia, Ulla Kasten and Elizabeth Payne, from the Yale Babylonian Collection, also made valuable contributions.

One of Rushmeier's latest projects, Hyper3D, further advances the goal of better access and cultural preservation.

Funded with a grant from the Seaver Institute, the program is designed to give conservationists a better workflow when documenting artifacts, artworks and archaeological sites. The software allows multiple researchers to work on the same item and post images and notes that are easily accessible to others.

"It will provide a common base so that everyone can access the information and know the provenance of that information," Rushmeier said. "Others working on the same painting or site can share data about what's effective for preserving things."

Simon said this means that a community of researchers can share information about pigments, damages or any other data that would otherwise get tucked away into a folder.

"This could bring the field of preservation to the next level," he said.

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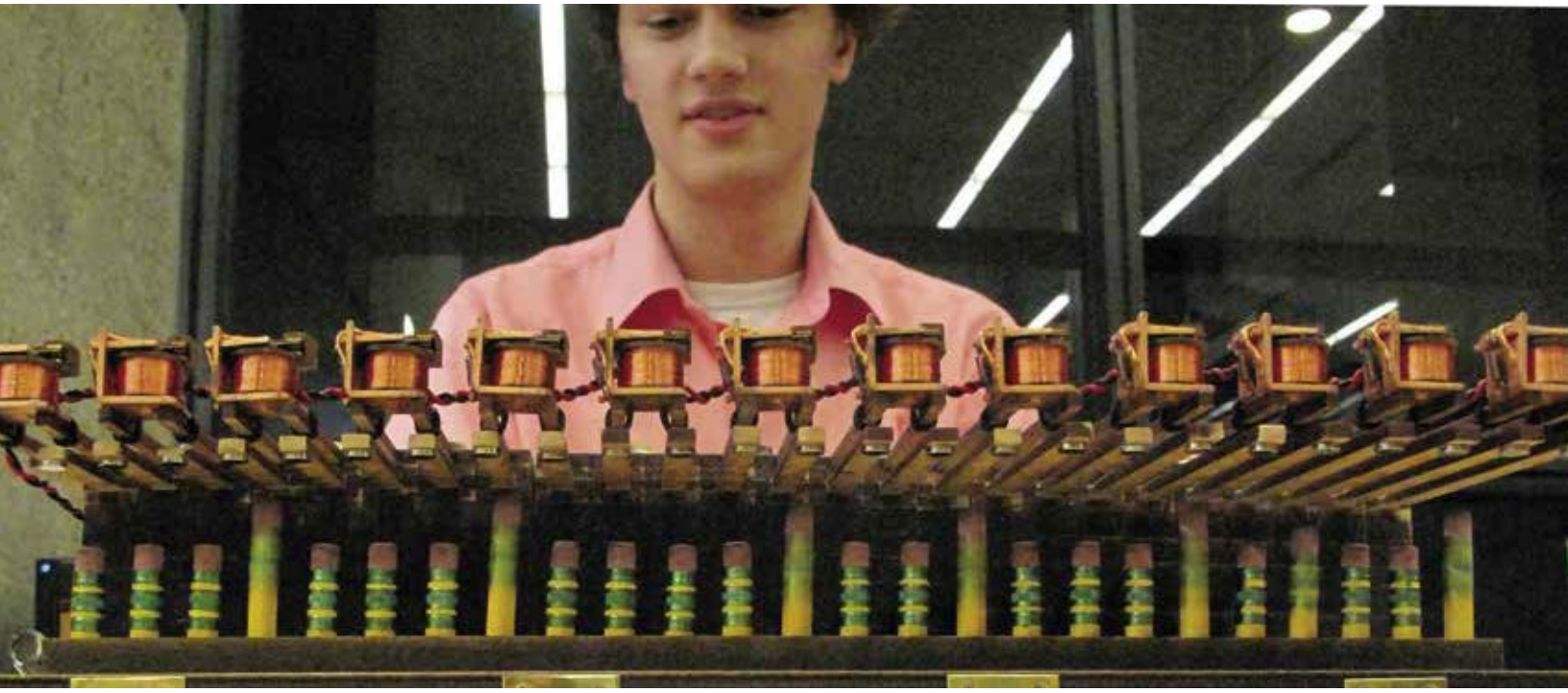


New Instruments, New Sounds

The Musical Side of Engineering

Yale

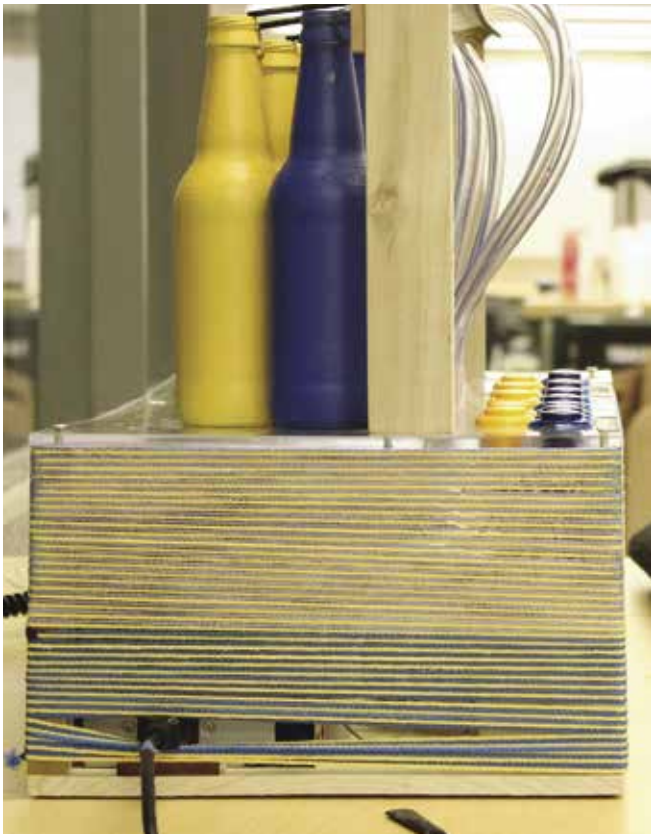
INTERDISCIPLINARY

"All the composers in Hollywood are looking for new sounds that stand out," said student Jordan Plotner. "So why is there no instrument that uses the beautiful sound of blowing across glass bottles?"

Answering his own challenge, Plotner built "Helmholtz's Harmonious Homebrew," a contraption comprising 12 glass bottles, each filled with "tuned" levels of water. He took on the tuneful project last fall for "Musical Acoustics & Instrument Design," a CEID class co-taught by Konrad Kaczmarek and Larry Wilen. Instructed to let their creativity reign, the students' each invented and built an instrument.

"The CEID ecosystem is essential to this class," said Kaczmarek, a composer and lecturer in the Department of Music. "Many of the students came up with instruments that could only be built in that environment with those tools — they built instruments they couldn't build in any other context."

The class fully embraced the spirit of creativity. Student Rachel Perfecto created "Clip-B-Audio," in which the performer creates an electric circuit by drawing lines on



Top: *Taking inspiration from the Fender Rhodes piano, percussive tones are generated from tuned wooden tines struck by pencil erasers.* Bottom: *"Plotner's Harmonious Homebrew" produces sound by blowing air across the mouth of 12 tuned bottles.*

Left: *"Potenciello" combines the technology of the theremin with the performance techniques of a cello.* Right: *"Siren Song" is a polyphonic keyboard that uses light to produce sound.* Bottom: *"Lothlóritar" was designed to only be playable by two performers working together.*

paper, connecting the pencil to a metal clip on a clipboard. The distance between the lines and the clip determine the musical notes. "I'm excited to show it to my friends who are art majors, just to see what they do with it," said Perfecto. "Or maybe this is how I'll take my notes in class from now on."

With its calliope-like tone, Plotner's Harmonious Homebrew, is easy on the ears, if not easy to make. "To mimic how air escapes out of the lips when blowing across a bottle opening, I took a lot of photos of my mouth," he said. "I was able to model the shape of my lips into a mouthpiece that I could make on a 3D printer."

By semester's end, students could use laser cutters, connect circuits, solder wires, and customize software to control microprocessors. Wilen, CEID design mentor and senior research scientist at SEAS, said the hands-on project drove home the lessons better than sitting in a classroom would have. "By the end of

Continued →

the course," Wilen said, "the musicians became incredibly skilled engineers, and the engineers were amazing musicians."

When Donya Quick hits a key on her laptop, there's a few seconds of silence followed by a lilting melody with a vaguely 18th century sound to it.

"The program's modeled after Johann Sebastian Bach, but it never gets exactly to Bach," said Quick, a lecturer in computer science. "Right now, it would pass a music composition class. It wouldn't necessarily get the top grade in the class, but the goal isn't really to beat people at their own game."

Quick has spent the last few years developing Kulitta, a software program that makes never-before-heard music. Algorithms generate new harmonies, chord sequences and melodies. A keystroke changes styles from classical to bossa nova to jazz. Quick said it could potentially be used for music education, or reveal things about musical grammar useful to the field of natural language processing.

It also gives Quick some good ideas when she's composing her own music. "There have been many cases where Kulitta came up with something interesting and I thought 'That is something I never would have done with my own set of composition tricks, but I like it.'"

Most reactions to Kulitta are positive, she said, but new technology rankles some people whenever it's applied to music. "No one gets up in arms about Siri talking to you, but I guess if Siri started singing, then all of a sudden, that's offensive."

Based on student feedback, though, she's not too concerned. "Students I've talked to were especially interested in Yale, because it's fairly rare to have this kind of project involved."

This fall, she's teaching an introductory course on computer composition. "I'll take people without necessarily any computer or music background and teach them to program and teach them some things about music at the same time," she said, adding that it's for anyone who likes music and is interested in programming. "So it's a really broad audience."

Quick said computer music is a perfect vehicle for bringing together two communities often seen as being on far ends of the academic spectrum. "I think it has attracted new audiences who might have felt shut out before, both from the computing and music communities," she said.

The Future of Engineering and the Arts

Julie Dorsey believes computers could transform arts education in general. At Yale, that's especially true now that the Computer Science Department recently became part of SEAS. That means more sharing of resources and know-how, said Dorsey, a professor of computer science. The department has had a Computing and the Arts program since 2008, and Dorsey expects the department's move to SEAS to bolster it significantly.

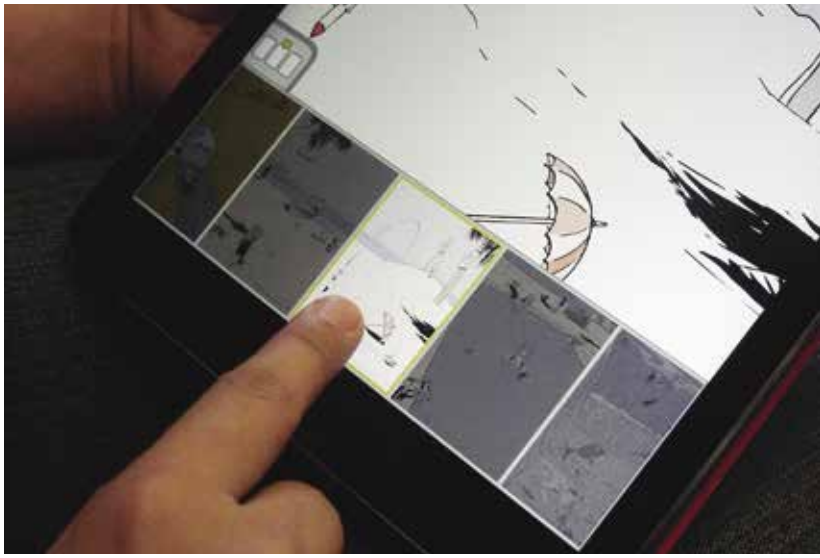
Dorsey's own work at Yale has focused on computers' contributions to the arts. Her latest project is designed to bring sketching into the digital age. As part of her software company, Mental Canvas, she developed a program that combines traditional drawing with 3D modeling.

With a background in computer science and architecture, Dorsey came to Yale in 1983, drawn by the "amazing riches" of its arts programs. If there's any university where engineers and computer scientists should branch out into the arts, she said, it's Yale.

The artistic approach can help engineers, who are traditionally taught to look for the "right" solution, Dorsey said. "Over on the other side of campus, they really follow the critique model of education, where multiple points of view are entertained. I think that model of education could be brought to bear on computer science and engineering."

Dorsey said she's seeing that happen more often at SEAS. Indeed, when mechanical engineers are working on experimental theater productions and students are using laser cutters to bring new clarity to French literature, it's safe to say that the lines between engineering and the arts are pretty well blurred.

"You're bringing together groups of people who think and work in completely different ways," Dorsey said. "And that is a really interesting possibility."



Yale

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