

## Biosphere Ecology

Postdoctoral scholar Kurt Dahlstrom studies the intimate relationship between bacteria and fungi in soils to demonstrate how fungi protect plants from harmful toxins. In a warming world, this work could be used to make crops more sustainable.



developed a new method to develop rechargeable batteries based on fluoride, which can last up to eight times longer than today's standard lithium-ion batteries.

Researchers at the Institute also have developed complex mathematical frameworks to map the energy grid across the nation, frameworks that will help determine when and where energy may be used most efficiently and where blackouts may occur.

### Next Steps:

Atwater says the group will focus on research that will:

- Turn solar and wind energy into baseload electricity as well as fuel sources
- Use solar power to produce cheap and energy-efficient fertilizers and fuels
- Make dramatic leaps forward in battery technology and efficient electrical grids
- Utilize machine learning to find new catalysts for chemicals, energy, and materials
- Develop commercially viable solar power that can be beamed from space to Earth
- Harness microbial biomass degradation to generate biofuels

### THE CHALLENGE:

## A Harmonious Biosphere

Many of Earth's organisms, from microbes to plants to humans, profoundly affect important global processes, including the flux of greenhouse gases into and out of

the atmosphere. Throughout Earth's history, no group of organisms has been more important in this respect than microbes; their metabolic activities have shaped the atmosphere, lithosphere, and hydrosphere over billions of years. However, in the past century, human activities have changed the earth's systems significantly.


The goal of the Ecology and Biosphere Engineering (EBE) initiative, led by Dianne Newman, is to understand how complex ecological relationships are affected by human activities and to identify means to promote more sustainable ecosystems. Specifically, the initiative will support research to advance knowledge of the distribution, abundance, and global impacts of diverse lifeforms on Earth; the physical, chemical, and biological interactions that define them; and how the control of particular organisms or communities may lead to desirable outcomes.

"A focus on ecology and biosphere engineering will be a new direction for Caltech," says Newman. "Though we have many interested scientists and engineers on campus, ecology is an area we have not traditionally studied."

Newman notes that Caltech's interdisciplinary Center for Environmental Microbial Interactions (CEMI) provides an example of the type of focus and collaboration that will characterize the EBE initiative. Members of CEMI, which has brought together more than 30 faculty from nearly every division since its inception in 2012, work on diverse problems that range from the control of methane by microbial communities in deep ocean sediments to the development of new tools for ultrasound imaging that harness microbial gas vesicles.

### Next Steps:

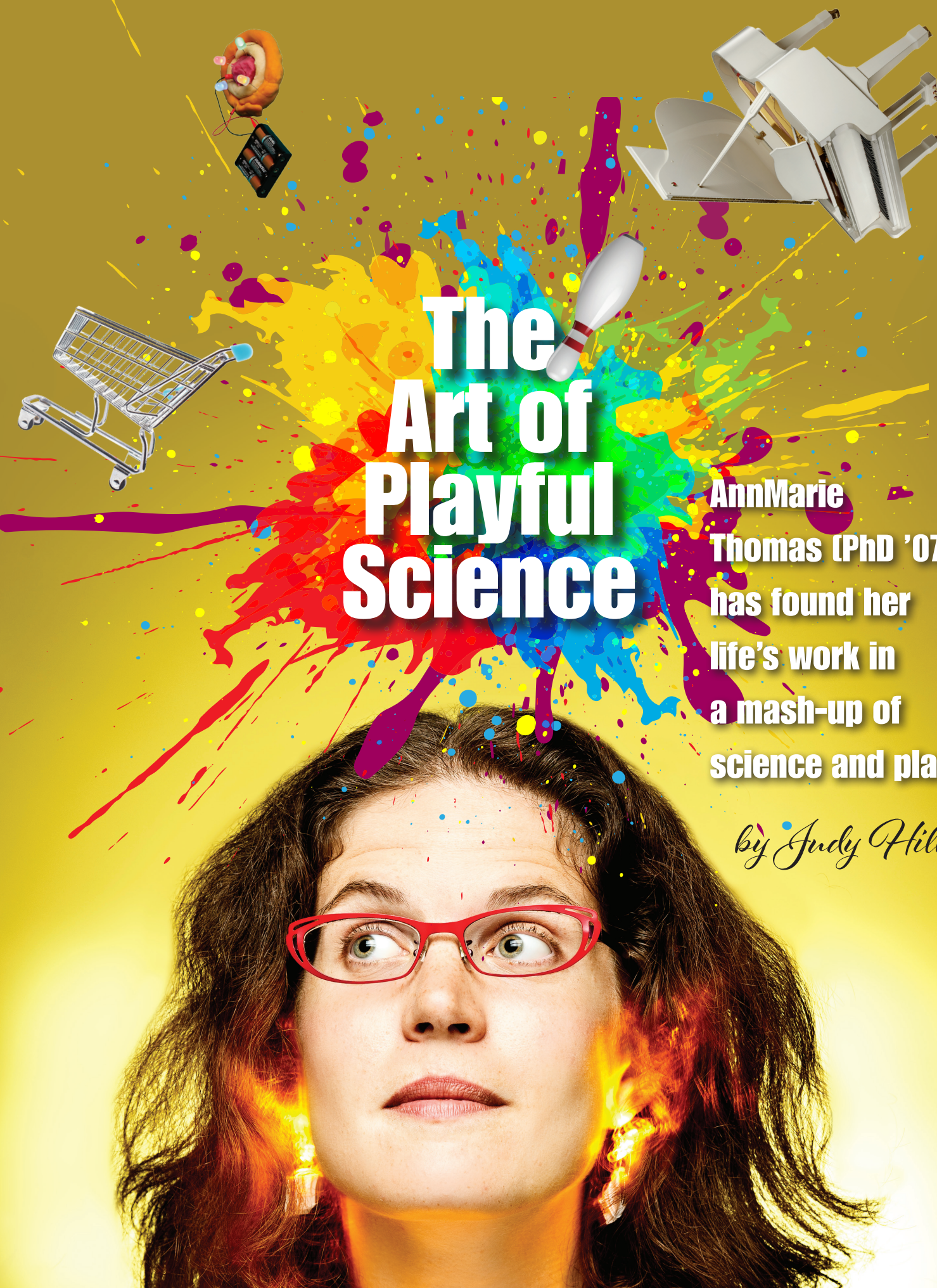
Areas for initial investment, says Newman, could include research that will:

- Develop more accurate ways to monitor and/or control certain species in ecosystems
- Develop real-time sensors to monitor ecosystem changes over diverse spatial and temporal scales
- Characterize soil microbial communities that associate with particular crops or forests in order to explore ways to bolster plant resilience in the face of increased drought or floods, to maximize nutrient retention and recycling, and to protect plants from pathogens whose ranges are expanding due to climate change
- Find ways to better model the terrestrial biosphere's contribution to the global carbon cycle to minimize negative consequences associated with fertilizer production, transport, and runoff.
- Engineer novel capabilities in photosynthetic organisms to make them more efficient at energy capture
- Devise new ways to make greener plastics 

# The Art of Playful Science

AnnMarie Thomas (PhD '07) has found her life's work in a mash-up of science and play.

by Judy Hill





AnnMarie Thomas partners with preschoolers and college students to design a project for the Works Museum, an interactive children's museum in Bloomington, Minnesota, that focuses on technology and engineering.

**At 10 a.m.** on a recent December morning in Beckman Auditorium, nearly a thousand L.A. County school children chuckle, whoop, and occasionally applaud as they take in the controlled mayhem playing out on the video screen in front of them. A minute and a half into a chain-reaction sequence worthy of Rube Goldberg, a soccer ball falls off the end of a track, hitting a plank, which causes a suspended piano to crash to the ground, which trips a lever that sends a shopping cart down a ramp, spewing its contents, which (eventually) unleashes a hanging sledgehammer that smashes a TV, which ultimately causes a row of cannons to splatter four white-overall-clad musicians with brightly colored paint.

The music video the middle schoolers are watching is “This Too Shall Pass” by the American rock band OK Go, and the four band members are onstage at Caltech to talk about how they created this and other videos throughout their 20-year career, including one filmed on a plane in microgravity and one shot in 4.2 seconds and played back in slow motion over four minutes (fully synced to the music). Bursting salt canisters, flying paint, exploding guitars, and erupting water balloons abound, but so do lessons in mathematics, physics, fluid dynamics, and parabolas.

The students’ questions range from “Did you feel like throwing up when you were in zero gravity?” to “How did you figure out the spreadsheet for the slow-motion video?” Gently guiding the conversation is AnnMarie Thomas (PhD ’07), a mechanical engineering professor at the University of St. Thomas in St. Paul, Minnesota, who also heads up OK Go Sandbox, a free website for educators that uses OK Go’s music videos as starting points for teaching children STEAM (science, technology, engineering, art, and math) concepts.

Thomas met OK Go lead singer Damian Kulash at TED2017 in Vancouver, British Columbia, when Kulash spoke about how the band comes up with ideas for its music videos. Thomas, who for years had included OK Go’s videos in her lesson plans, bumped into Kulash as they were both grabbing a cup of coffee after the talk. She told Kulash how much she enjoyed his presentation, and three weeks later they gave a joint talk at UCLA and had started to put together the OK Go Sandbox venture. In less than three years, they have produced almost 20 educational videos and a host of additional material for teachers.

If that sounds fast, for Thomas it is normal operating procedure. “When I like a project, I move fast,” says Thomas. “And I have an amazing student research team.”

On the faculty of the University of St. Thomas since 2006, Thomas co-founded and co-directs the university’s Center for Engineering Education. She also is a professor of entrepreneurship in St. Thomas’s business school.

Through her research group, which is called the Playful Learning Lab, Thomas and her team create hands-on experiences for pre-K–12 students and educators. Thomas also is the inventor of Squishy Circuits (a method for using homemade conductive and insulating doughs to sculpt electrical circuits) and the author of several books including *Making Makers: Kids, Tools, and the Future of Innovation*.

In her spare time, Thomas, who also has a certificate in sustainable design, is an avid aerialist, a juggler, and, during summers in her native New Jersey, a surfer. She and her husband, Chris Thomas (PhD ’04), a research chemist, have two daughters, Grace (9) and Sage (12), and whenever the family members’ downtimes coincide, they play board games together in their St. Paul home or spend an afternoon in a local puzzle or escape room.

Working with OK Go seemed like a natural fit to the playful and energetic Thomas. “The band knew that teachers used their videos,” she says, “and that made them super happy, but they also knew they were musicians, not educators.” Thomas and her lab provided the missing expertise, surveying teachers and zeroing in on topics and themes to explore through educator guides. It was that work, in collaboration with OK Go, that resulted in OK Go Sandbox.

“Damian is one of the most creative people I have ever met,” says Thomas. “Quite a polymath.” Their work style is to chat frequently, run ideas back and forth, and then get together with the band and a film crew, usually in L.A., to shoot segments for OK Go Sandbox.

For “This Too Shall Pass,” the Rube-Goldberg-inspired music video, the team put together a behind-the-scenes video. “We wanted to encourage kids to make their own chain-reaction machines,” says Thomas. “And I wanted to look more closely at simple machines. You can use this whole video as a simple-machine scavenger hunt, so we have that in the teacher resources.”

When the team films educational videos, they always have at least one teacher on set, and every resource guide developed by OK Go Sandbox is play-tested by teachers and then tweaked in response to their feedback. “People think we do the stuff for the kids. And it’s true,” says Thomas. “I love kids, but really my heart is in how we can give educators ways to enjoy what they’re doing, to be engaging and engaged with the material.”

Thomas is equally focused on giving her undergraduate students once-in-a-lifetime experiences. The Playful Learning Lab is completely staffed with undergraduate students, approximately 30 in all, and they are a diverse group. “About a third are computer science or engineering students,” says Thomas, “and the other two-thirds are

Previous page: AnnMarie Thomas, wears a pair of homemade LED earrings. In the upper left, just above the headline, is a Squishy Circuit, one of Thomas’s inventions.

students from a mix of communications, journalism, education, business, finance, marketing, and music.”

Krista Schumacher, a junior majoring in elementary education at the University of St. Thomas and a lead education researcher for the Playful Learning Lab, says, “AnnMarie has taught me a multitude of things, but the most important is the ability to apply each person’s unique strengths in our work.” For Schumacher, that has translated into designing exhibits at the Minnesota Children’s Museum and working on a mathematics-

Members of the rock band OK Go experiment with zero gravity in their music video “Upside Down & Inside Out.”



educator guide to accompany OK Go’s slow-motion “The One Moment” music video.

Collin Goldbach, a senior in mechanical engineering and lead engineering researcher for the lab, has worked on projects as diverse as embedding sensors and microcontrollers to accentuate the performance of trapeze artists and building life-size pop-up books for exhibits at local children’s museums. “While we all have some capacity to bring change, the effect when we work together is greater than the sum of its parts,” says Goldbach, who then adds that he learned that lesson from Thomas.

As a St. Thomas undergraduate, Rachel Gehlhar worked with Thomas on a project with Chicago’s Michelin three-star restaurant Alinea to measure the organic volatiles of black and white truffles. She says Thomas gave me “oppor-

tunities as an undergraduate to lead a graduate-level research project and connected me with people I couldn’t have dreamed of meeting on my own.” Gehlhar is now a graduate student at Caltech in the lab of another St. Thomas alum, Aaron Ames, Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems.

Play, in the Playful Learning Lab, is defined by Thomas as “joy, whimsy, surprise, and new people.” The lab rules are: “Be kind, play well with others, and clean up your messes.” By having her students take responsibility for marketing, budgets, travel, and lab operations, as well as for the research and design work, Thomas hopes to help them develop competency in many areas.

She says she is less concerned with her students’ grades than with the meaningful work they are accomplishing. When she was a student herself, Thomas says, she excelled at doing projects in classes because she was able to organize and bring together the right mix of people. “If the class didn’t have a major project component, though, whether it was a physics class or a math class, I struggled and did not get an A and probably did not even get a B.”

As a child, Thomas had widely varying interests (“I was a little odd,” she admits) and in high school was convinced she would be a painter or an actress or a musician. Her bachelor’s degree from MIT was in ocean engineering, but she earned a minor in music composition. And while at Caltech, though her PhD was in mechanical engineering, she also took classes at ArtCenter College of Design, even becoming a faculty member there in her third year of graduate school, teaching bioinspired design and robotics as well as collaborating on installation artwork with exhibitions director Stephen Nowlin.

Though Thomas was hardly a typical Caltech graduate student, she says the experience worked for her largely because she found an understanding adviser in mechanical engineering professor Joel Burdick, who “let me do a lot of things.” Burdick, who calls Thomas “a tornado with glasses,” says he knew early on that she was interested in teaching and public outreach, and encouraged her teaching at ArtCenter as well as her leadership role with the Caltech Robotics Outreach Program. He is not surprised that his hardworking and productive graduate student, whose thesis involved robotic jet propulsion, has continued to lead and innovate. “What does surprise me,” he says, “is her ability to juggle so many different things.”

As Thomas tells it, she began to find her true calling after the move to Minnesota, when she invented the conductive, insulating Squishy Circuits as a way for her daughter to play with circuitry. When that took off, she began to realize she had found her sweet spot. At around the same time, she taught a class on the physics of circus

arts, where she had students learn circus skills and then wear sensors while they performed, and later analyze the data they recorded. “And once you’re that professor, then other weird things start happening,” says Thomas.

Thomas glows with pride as she talks about Code + Chords, the software project students in her lab have created, and the awards and published papers that have resulted from this open-source coding library that creates real-time visual displays based on vocal inputs. She lights up still more when she describes the science workshops her students have conducted at the Metro Deaf School in St. Paul and how the students there are now learning to code using the music software from the earlier project.

Add to that a newly established five-year residency at the Minnesota Children’s Museum, where Thomas and her team spend one day a week studying how families interact in the museum and designing new exhibits and experiences, plus a partnership with Jeff Bezos’s space company Blue Origin that will send children’s art designs into space, and it is not hard to see why a colleague recently said to Thomas, “I’d be happy with just one of your projects.” “So would I,” replied Thomas wryly, though she also believes that as stand-alones they would have less impact.

“All the projects I do are related,” she says. “Learning is about curiosity and pulling together unusual things. How do you take things that seem unrelated, be they music and coding, physics and circuses, rock stars and preschoolers, or chemistry and chefs, and smash them together in new ways? That’s our happy spot: we take all these different things and try to see them in new ways.”

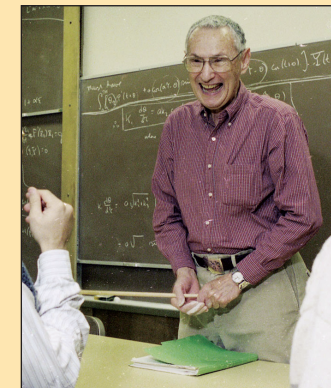
As much as her work focuses on play, Thomas takes collaboration seriously. Too often, she says, people say they collaborate when they are simply calling on someone who has the right piece of software or knows the right math equation. “That’s not collaboration,” she says, “that’s consulting.” She will only agree to a project when she has had a “playdate” with the people involved, and they have started to dream up ideas together.

Naturally, given Thomas’s personality, those early get-to-know-you sessions often end up being playful. When her team was considering working on a music-visualization software project with an a cappella group, she insisted on meeting every member of the group first. “I got to the coffee shop before them and wired up the coffee spoons to a circuit board so they could play music with their spoons,” she says. “With everything I do, it’s about how you bring play to a situation, whether it’s a course or a topic or a project.” Or a meeting with an a cappella group about software. ☺

Learn more about OK Go Sandbox and watch OK Go videos at [okgosandbox.org](http://okgosandbox.org)

# In Memoriam

Read more about their lives at [magazine.caltech.edu/post/in-memoriam](http://magazine.caltech.edu/post/in-memoriam)



## Donald S. Cohen 1934-2020

Donald S. Cohen, Charles Lee Powell Professor of Applied Mathematics, Emeritus, passed away on January 9. Cohen was one of the first faculty members recruited for Caltech’s newly formed applied mathematics program in 1965, earning tenure in 1971. Colleagues and former students remember Cohen’s outgoing personality, quick wit, and engaging lectures. Cohen’s research on nonlinear differential equations, pattern formation, stability, and bifurcations had a significant impact on mathematical biology and chemical engineering.



## Shirley Marneus 1935-2020

Shirley Marneus, who founded Theater Arts at the California Institute of Technology (TACIT) and directed stage productions at Caltech for more than 20 years, died on January 13. Before coming to Caltech, Marneus worked for the Pasadena Playhouse and NBC’s *Jack Benny Show*. Marneus created TACIT in the mid-1980s to provide students a formal theater program with a didactic purpose as well as an entertainment purpose.

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