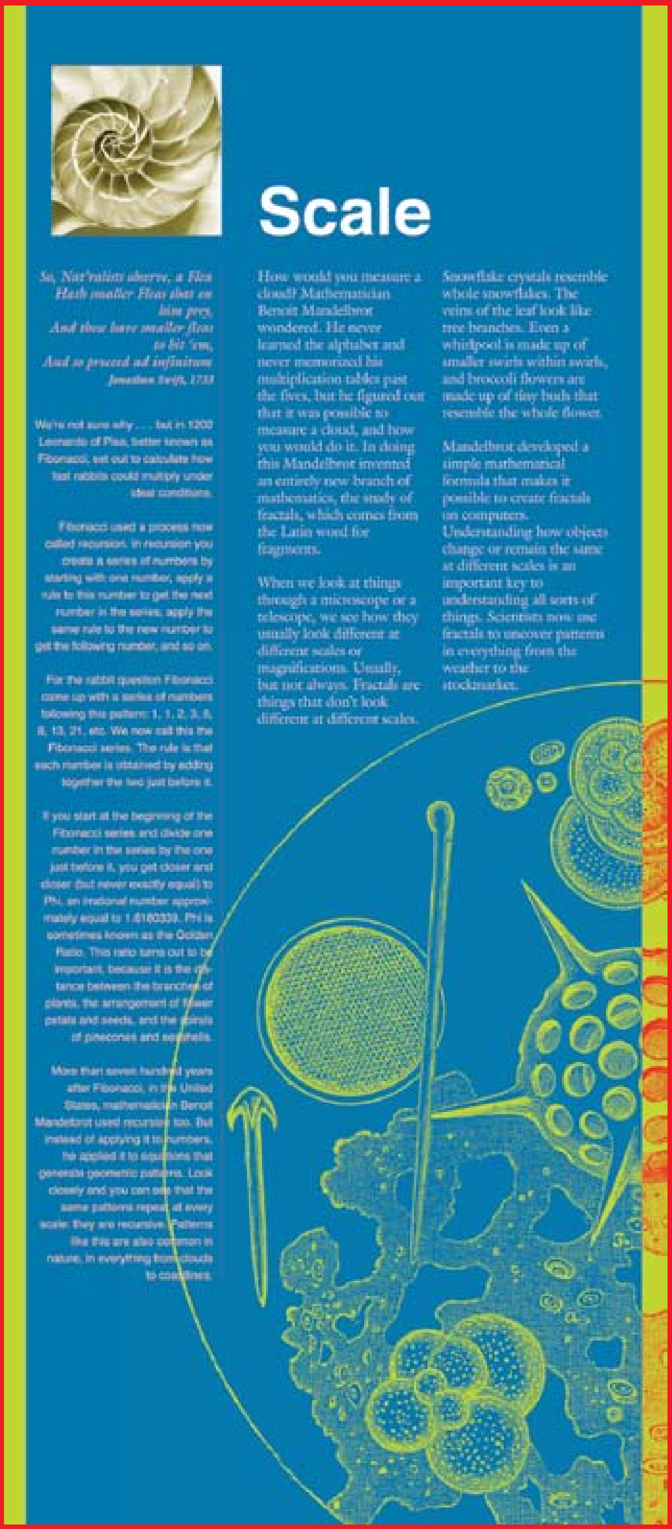

This mobile exhibit panel is one of many explaining complexity themes. It's used as a learning tool in schools and at events.

Learn@santafe.edu Creates a Blueprint for Complexity Science Education

By Janet Stites

Since its genesis, the Santa Fe Institute has always had an informal mandate to educate others about the science of complexity and illustrate how computer modeling could be used as a tool to study a plethora of systems, ranging from the immune system to political networks. But until recently that effort was more reactive than proactive, and for the most part, targeted at graduate students, postdoctoral fellows, and the local Santa Fe community. Now that's changing in big ways.

The Institute's first concerted effort at education was the creation of the Complex Systems Summer School (CSSS), a month-long summer program in Santa Fe. Launched in 1988, the four-week school for graduate students and postdocs provides an intensive introduction to complex behavior in mathematical, physical, living, and social systems. Over 1,200 students from all over the world, representing various disciplines, have participated.

The goal of the program, which is free of charge, is for students to gain a working knowledge of the intricacies of complexity science and a grasp of how to use some fundamental tools for its study. Since 2000, with support from its International Program, the Institute has launched mirror schools first in Budapest and more recently in Beijing.

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Eric Smith, Shelley Copley, and Harold Morowitz discuss the Institute's work on the Origin of Life. This subject is slated for development as an education module.

SFI found another, predominantly non-scientific, audience in the local community, launching its free, monthly public lecture series 15 years ago. The series regularly attracts 200 to 400 people from the Santa Fe area per program. The flagship event of the annual series is the Stanislaw Ulam Memorial Lecture Series, which has hosted such luminaries as Distinguished Research Professor Geoffrey West, Nobel Laureate Murray Gell-Mann, Harvard University's Richard C. Lewontin, and others.

These initiatives, along with postdoctoral, graduate, and undergraduate fellowships, and the Institute's ongoing scientific workshops—which all have an explicit mandate to include students—have created a global network of scholars and lay people familiar with complex systems studies.

But SFI recognizes that many students don't even hear the phrase "complexity systems science" until graduate school and that complexity science as a whole is yet to become part of the global consciousness in terms of science education. In response, it has turned its attention to a broader audience, both age-wise and geographically, through a new program dubbed learn@sfi.edu.

Modeling Adventures

With SFI's Ginger Richardson serving as coordinator, learn@santafe.edu will operate as an umbrella for numerous initiatives, all primarily addressing the importance of complexity science education, and secondarily, the value of teaching computer modeling skills. Richardson already has a world-class collection of scholars from both the sciences and education to help develop and execute programs worldwide.

Central to the effort is the work of SFI Science Board member Eric Klopfer, who is on the faculty at the Massachusetts Institute of Technology. Introduced to the Institute in the late 1990s by his mentor Mitchel Resnick, Klopfer has already made a ripple among science teachers nationwide and in Canada with his "Adventures in Modeling" (AIM) workshop series.

Backed by a series of National Science Foundation grants, and developed with the help of MIT's Resnick and Vanessa Colella, this approach is not focused per se on complexity science, but on showing secondary and middle school teachers how they can implement computer modeling—in the form of agent-based games—in their classrooms to teach an array of subjects ranging from biology to economics to theories of cooperation, and demonstrate how the models can be used for problem solving.

The games are based on Resnick's concept of "decentralized thinking" as exemplified by the models constructed in his StarLogo modeling environment and described in his book *Turtles, Termites, Traffic Jams,* which help students learn about decentralized systems and emergent phenomena. They are perfect fodder for Klopfer, a biologist turned educator.

"The agents interact with their environment—animals eating grass, molecules of water interacting with a box," Klopfer says. "The goal is to get students thinking about complex systems through programming."

The team has now developed a set of games which emulates viruses, ecosystems, genetics, and economies to teach concepts such as emergence, cooperation, competition, and robustness. Originally they ran on small wearable computers, which looked like nametags. The tag would light up to indicate an action such as when the wearer was infected by a virus. Now, however, they are run on Palm-based personal digital assistants.

Klopfer and his team have hosted dozens of workshops in Santa Fe, Boston, Toronto, Boulder, Mexico City, and elsewhere, and an ad-hoc community of teachers have become regulars, incorporating the games into their own classrooms and/or becoming workshop facilitators themselves. The goal is to secure funding to be able to host more workshops and allow more teachers to participate in their classrooms.

Problem Solving with Complex Adaptive Systems

Susan Yoon, an assistant professor at University of Pennsylvania's School of Education, participates in the program and has become not only a facilitator, but an integral member of the team. Raised and schooled in Toronto, Yoon, like Klopfer, is a biologist, but eventually ended up in education. "I was an anti-racist educator, working with an urban immigrant population, teaching science," she says. "Because of our push toward content and testing, learning about scientific issues like values, attitudes, and ethics fell by the wayside. I began to see that a number of circumstances needed to line up for any change to take place."

She recognized that complex adaptive systems (CAS) served as a way to think about problem-solving and that modeling and simulations were a primary way to study them. She immersed herself in literature dealing with non-linear systems and eventually her dissertation

LIVE ADVENTURES IN THE CLASSROOM

The Santa Fe Institute's "Adventures in Modeling" collaboration with the Massachusetts Institute of Technology (MIT) Media Lab has trained numerous teachers how to create models based on complex adaptive systems science and how to incorporate these models into their classroom teaching. Unfortunately, no matter how much enthusiasm the teachers have when they leave the workshops, it's often difficult for them to find the time to implement them, especially in light of meeting requirements for standardized tests. Finding sufficient financial support from their administrators is also an obstacle.

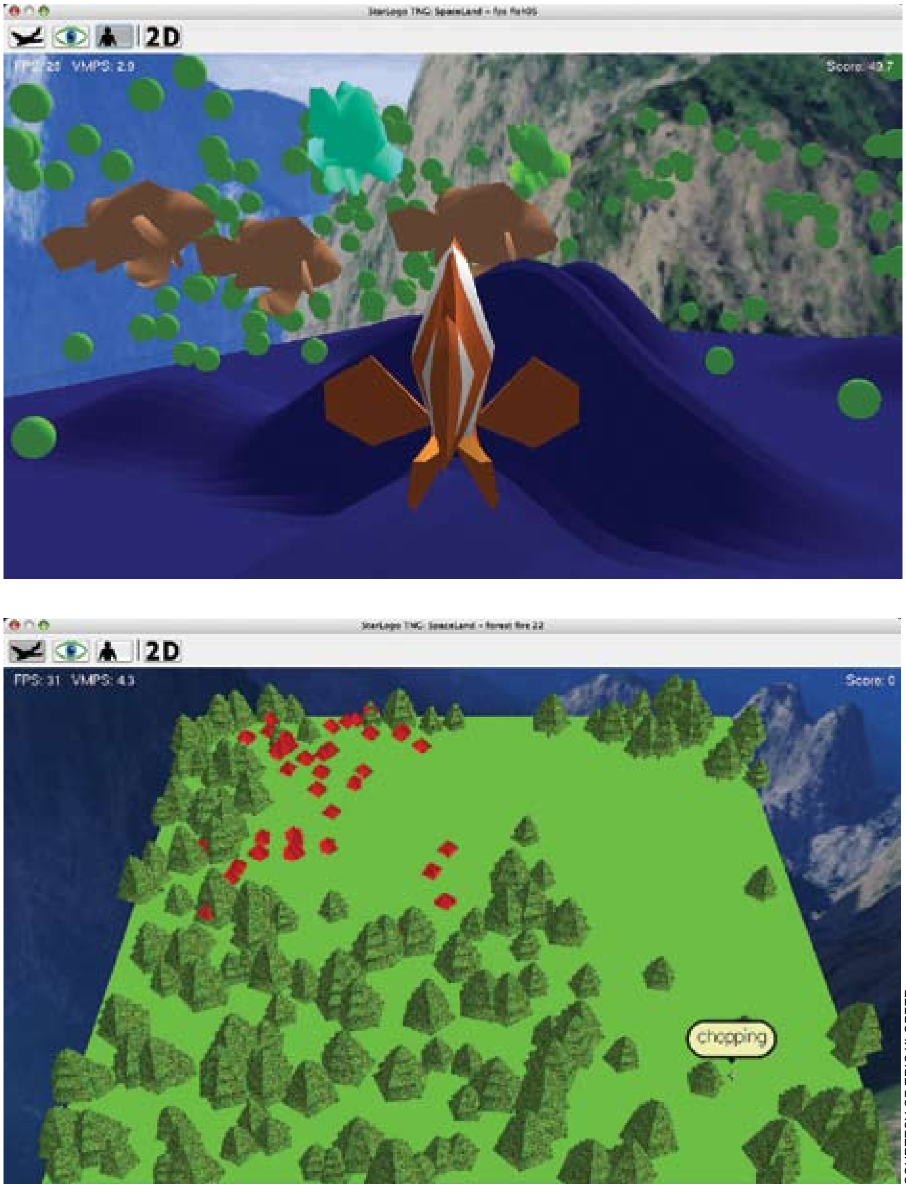
But this hasn't stopped workshop participant and Boston-area high school science teacher Julie Boehm, whose students are thriving on the MIT games in her classes. She first heard about the "Adventures in Modeling" program while she was a student of education at Harvard and then again from another teacher while she was student teaching. She used some of the research in her ninth- and tenth-grade classes and, subsequently, hooked-up with MIT's Eric Klopfer for a personal workshop. Since then, she has been using three of the games as part of her curriculum: "Live Long and Prosper," "Big Fish, Little Fish," and "Virus," with MIT loaning her the necessary Palm Pilots.

"The games are very engaging for the students," she says. "When they play one, it hooks them. Whether they realize it or not, they're observing and analyzing. It's a problem they want to solve."

Boehm says that her quiet and underachieving students often do the best job. "Their observations are more attuned," she says. "They are not trying to figure out if someone is trying to put something past them."

During the simulations, Boehm is careful to position herself as a facilitator, as opposed to taking a more traditional teacher/student approach. She lets her students discuss their ideas and strategies for problem solving among themselves.

Because of Boehm, other teachers in her school have been able to incorporate the games into their classrooms too, but only on a limited basis because of lack of funding. The program is invaluable, says Boehm. "The games reinforce the scientific concepts more strongly than anything else I've tried."



COURTESY OF ERIC KLOPFER

Top: In this StarLogo-TNG model of predator-prey dynamics, fish need to eat plankton to survive and reproduce. The model user leads schools of fish to food that may be spatially isolated to simultaneously study ecology and behavior.
Bottom: In this StarLogo-TNG model of forest fires, the character in the corner, controlled via keyboard or joystick, clears parts of the forest to try to limit the spread of fire. The model user controls wind speed and forest density to study differences in these parameters.

supervisor introduced her to Colella at MIT. At the first "Adventures in Modeling" workshop she attended, she played the virus game using the thinking tags. Ultimately, she incorporated them into her dissertation, which focused on decision-making in regard to genetic engineering.

"The simulations and modeling were new," she says. "I could see why visualization—in terms of students being able to see other people's perspective—was helpful. And the feedback signal was very important to me. We don't think about it, but even what we wear—like a baseball cap representing our favorite team—signals to others our positions and beliefs."

Yoon continues to be involved with the "Adventures in Modeling" team. Meanwhile, back at Penn, her own work focuses on developing a framework to improve teacher and student understanding of computational modeling tools. For that she has developed what she calls FANS: Feedback Adaptation, Network Growth, Self-organization, borrowing from complex systems design principles. In a three-year study, she has found evidence to show that the FANS framework encourages professional goal setting, engagement in a strong professional community, and personal autonomy by enabling individualized purpose—all fundamental components in promoting self-organization.

In Silico Science

SFI program manager and Santa Fe high school science and math teacher Atty Mullins is also working with learn@sfi in several ways. He's part of the "Adventures in Modeling" team, serving as both a thought leader and practitioner, using his own classrooms as a place to hone the curriculum.

The project meshes perfectly with Mullins' experience, interests, and concerns as an educator. "In the future, the way we'll do science will be more computer-based 'in silico.'" he says. "People will be running simulations on the computer. Complex systems lend themselves well to modeling, and SFI does a lot of modeling."

How he ended up on the team is a bit serendipitous. He too had been at the MIT Media Lab in the early 1990s, was familiar with Mitch Resnick's work, and had toyed with StarLogo. But he left the lab and moved to Santa Fe with his wife, who had family in town. He worked long-distance for a software company for a few years and then began to teach science and math. Through his teaching, another local Santa Fe teacher introduced him (again) to StarLogo and the "Adventures in Modeling" program. He immersed himself, quickly becoming part of the AIM team and, eventually, became a facilitator.

Complexity Allies

But Mullins plays a larger role in SFI's education effort, serving as the point person for the "Alliance for Complexity Science," (ACE) which has created a national constituency of scholars interested in promoting complexity science studies at all levels. Formed last year, its members include educators and scientists from SFI, MIT, University of Michigan, University of Pennsylvania, and University of Pittsburg. Its mandate is to call for science reform in our schools in response to the U.S.'s dismal record—in relation to other developed countries—on teaching math and science.

The committee is small and its task monumental. Recently members took a step to self-organize into affinity groups to cover a wide range of areas with the following titles: Philosophical Issues, Learning Science, CAS Concepts, Modeling & Simulation, Mental Models, Systems Thinking, and Interdisciplinary and Integrative Learning. For each they have identified four clusters where they want to take action: 1) curriculum design, 2) standards mapping, 3) research, and 4) implementation. As well, they plan to put into place a way to evaluate their efforts and create a list of places where they might seek funding.

The hard question is, How do you get from idea to implementation? At the local level, SFI researcher and "Adventures in Modeling" facilitator Irene Lee is spearheading an effort called "ProjectGUTS: Growing Up Thinking Scientifically" in conjunction with New Mexico's Supercomputing Challenge, MIT, the New Mexico Institute of Mining and Technology, the Santa Fe Public School District, Santa Fe Independent schools, science-related local businesses, and local science centers.

Having secured a grant from the National Science Foundation, the program plans to offer 200 middle school students (particularly targeting area Hispanic and Native American students) an after-school curriculum in which they will study science, take field trips, interact with local businesses in the scientific field, and participate in a free two-week summer session, to be held in the Institute's gatehouse. There they will create their own models based on the world around them. In an effort to have elements of the program incorporated into curriculums, 40 area teachers will be trained as club leaders.

"The impetus for GUTS came from a project we did with the Supercomputing Challenge in local Native American communities," Lee says. "We went out to the pueblos to work on some modeling initiatives. We found the students were really drawn in

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A new program will evaluate the Complex Systems Summer School to determine its effectiveness. Here, the 2006 CSSS faculty and participants enjoy the Santa Fe sunshine.

if the models were pertinent to their community—as opposed to modeling the trajectory of a comet, for instance."

The kids created models on how to handle the invasive, non-indigenous olive trees which were blocking their water ways, how to restore the native flora, and how to handle the stray dog problem which plagues the pueblos (in this model they wrote programs in which dogs were neutered or spayed).

Lee worked on a similar project with a number of Santa Fe schools—again having the students focus on real-life problems within their schools' ecosystems. For this effort, the students created a number of models, including one to monitor traffic flow in their school parking lots, gauge the spread of flu through their schools, and see how many garbage cans a school needs to keep trash off the floor. In the latter one, the students could see how much of a mess one person can cause throwing trash on the floor, even if 99 others are picking it up.

Students also created a model of the flow of a local river. "It had dried up over the last two generations," Lee says. "In order to create the model, the students spoke to residents who had lived there for a long time to ask them what it had been like, finding out what types of plants grew nearby when there was water. They even spoke with a city planner." At the end of the project, the kids shared the models with each other on a school-by-school basis.

Complexity for the World

What keeps Derek Cabrera up at night is contemplating how to create a platform to bring complexity science education to a national and even global audience—at all levels. This SFI research fellow and Cornell University postdoc in the College of Human Ecology also wonders how the Institute can leverage its deep library of knowledge and resources, getting researchers off the campus and into the global scientific thought process at all levels.

Cabrera, who works closely with Richardson, Klopfer, and Mullins, and is also part of the ACE initiative focusing on evaluating programs, is acting as a producer of sorts to create multimedia modules

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In 2006, these students worked at SFI as part of the annual National Science Foundation-funded Research Experience for Undergraduate Interns program.

which can be parsed together depending on topic and age group to be incorporated with any seminar dealing with complexity science.

The first production he's working on will be incorporated into an SFI teaching module on Network Theory. Working in conjunction with Columbia University sociologist and postdoc Michelle Girvan and others, Cabrera has created a template for a four-day lecture series. The key feature is its modular structure, which allows facilitators for each section to give a self-contained presentation, depending on their backgrounds and needs.

The program will use various elements—graphics, videos, animation, audio, photographs, film, and interactive games—to be matched with a facilitator's notes. This allows the series to be portable, held anywhere in the world without having all the key participants on site. Such a structure makes it easier to adjust the content for presentation to a specific age group, a non-scientific audience, or a group of postdocs in a specific field. For the Institute, the modules can be used for all its varied audiences, including the middle school kids, the Business Network, and the Complex Systems Summer School program.

As noted above, Cabrera's other contribution to the push for complexity science education is to create a system of evaluating programs. Working with a team at Cornell, he has created The Cornell Systems Evaluation, Evaluation Systems Project (SEES), which is a 2-year NSF-funded initiative aimed at developing evaluation tools for science, technology, engineering, and mathematics (also boasting its own acronym: STEM).

> "Twenty years ago, SFI's approach to complexity science was relatively unknown...Now it's well recognized. We look forward to engendering the same sort of changes within the world of education."

SEES' first year has focused on developing a theory and working protocol of systems evaluation and evaluation systems. In its second year, SEES will pilot-test its theory and protocol with three existing STEM programs, including SFI's Summer Schools, both in Santa Fe and Beijing. This is important to SFI because in the past the Institute only had anecdotal information about how the program informed the students' future work. "We want to know if the Complex Systems Summer School changes their perceptions and is a part of their ongoing work," SFI's Richardson says. "No one has ever done a long-term study."

For Cabrera, evaluation is essential to the process. "We can generate age-appropriate curriculums—content-wise—but how do we evaluate the long-term effect in terms of the students working in an interdisciplinary environment?" he asked. "It's difficult to know if we've changed the way they think about the world."

SFI's efforts coincide with wider trends, such as a growing appreciation of an interdisciplinary complex systems approach to science and the promotion of "dry" labs. These are labs in which students create computer models to run tests, as opposed to using the traditional wet labs with Petri dishes, beakers full of chemicals, and gas burners.

The Institute is looking to the resources it already has to help build-out its learn@sfi.edu program—such as the people who have been affiliated with the Institute over the last two decades. A 20-year reunion of CSSS students is being considered as a way to kick-start a long-term education initiative. But the team is not naïve to the challenge of changing the way science is taught as a whole, the bureaucracy of the system, and the weight standardized tests carry in terms of the curriculums teachers use and if they are even allowed to vary from them. "I think we will—eventually," responds Richardson. "After all, twenty years ago, SFI's approach to complexity science was relatively unknown within the research community. Now it's well recognized. We look forward to engendering the same sort of changes within the world of education." ◀

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