BUILDING A LEARNING CONTINUUM FROM SCRATCH

BY GINGER RICHARDSON, McKinnon Family Vice President for Education and Outreach, Santa Fe Institute

Right: Ginger Richardson. Above: Summer C.A.M.P. (Computation and Modeling Program) is a two-week residential science program for high school students that combines field research, lectures and seminars, and data analysis.

This is the story of educational outreach at the Santa Fe Institute: how we began with a grand vision, thudded back to earth, and then – through doggedness, windfall opportunities, an unanticipated digital revolution, and sheer luck – coaxed a program to emerge that is surprisingly resonant of the original idea.

The conversations among SFI's founders in the early 1980s envisioned SFI on a Rockefeller University model – a research institute offering accredited graduate education. "Teaching would be accomplished mostly in seminars and short series of lectures, but, above all, by means of apprenticeship and research," wrote Murray Gell-Mann in "Emerging Syntheses in Science," the volume memorializing the Institute's founding workshops.

At the time, Gell-Mann estimated that "three units" (a unit being $100 million) would be sufficient as an endowment to get the Institute off the ground. Unfortunately, such monies were not forthcoming. The research program would begin, but a student campus would have to wait. Further, the administrative hurdles of the accreditation process loomed larger than anticipated. Without specific funds for outreach or prospects for a campus, with no apparent legitimacy, and without obvious access to students (only a few of the Institute's founders were at universities), SFI's original Big Plan for education soon needed a reset.

Despite these logistical obstacles, George Cowan and his founding colleagues had some strong intangibles in their favor. Most important, they had a clear mission; scholarship would focus on the transdisciplinary study of complexity, a concept that provided a broad canopy for exploring various systems.

Second, they knew they wanted to initially target graduate students and postdocs – for both selfish and altruistic reasons. Scientists at this early-career stage could be trained relatively quickly as practitioners of complexity science – and become future ambassadors for the new approach.

Third, although the founders were not teaching experts, they agreed on several pedagogical

RIGHT: MINESH BACRANIA PHOTOGRAPHY; ABOVE: SFI ARCHIVES

SFI ARCHIVES

SFI's Research Experiences for Undergraduates program, supported by the National Science Foundation, offers a summer-long immersion in complex systems science. Participants work closely with Institute faculty on individual and small-group projects.

principles: students would work in multigenerational, collaborative groups; theories and toolkits would be drawn from a range of disciplines; and active learning would be the model – students would learn science by doing science. These elements have been intrinsic to SFI-style education ever since.

Finally, the founders had remarkable social resources at their disposal, including robust intellectual networks, strong institutional and personal convening power, and no lack of self-confidence.

When in 1987 Harold Morowitz called with an educational proposition, the Institute – despite its fledgling state – seized the opportunity. Morowitz, at Yale at the time, had the prescient idea of building a biology-wide information system with the ultimate end of pushing theoretical biology forward. He proposed convening biology, computer science, and information system grad students at a "Matrix of Biological Knowledge" summer school to begin this work.

Morowitz wrote a National Institutes of Health proposal that included support for student participants and – because we had no equipment – also funded a dozen workstations. We put an ad in *Nature*. Morowitz and his co-organizers, James Willet of NIH and Temple Smith of Harvard, tapped into their networks to recruit students. Classroom and dorm space were rented from nearby St. John's College (a relationship we continue to this day for SFI summer schools).

In hindsight, "Matrix of Biological Knowledge" turned out to be a seminal event in the emerging field of bioinformatics; many of the participants are now among the leaders in biological computer informatics and large-scale databases. Multidisciplinary, collaborative, and research-based, its organization and format was a proof-of-concept for future SFI schools. Most important, we pulled it off.

While Matrix was taking place, Institute founders were spearheading the first-ever Complex Systems Summer School (CSSS). Started in

1988, the annual, month-long residential event continues today and is the central node of SFI's educational programs. Every June, CSSS provides an intensive introduction to complex behavior in mathematical, physical, living, and social systems to some 65 graduate students and postdoctoral fellows. The school drives new complexity science content, pedagogy, and novel educational formats.

More important, CSSS is a community-building event. The summer school alumni roster reads like a Who's Who in complexity science. Lecture invitations strengthen existing faculty relationships and draw new collaborators. SFI undergraduate interns get their first immersion in the field, and postdoctoral fellows gain teaching experience there. Many of our postdocs come to us through the portal of CSSS.

John Miller attended the first summer school in 1988. He also was the Institute's first postdoctoral fellow. His ensuing career accomplishments and long-term SFI connections make him an SFI education program poster child. Now a Professor of Economics and Social Science at Carnegie Mellon, he has spent several extended residencies here. For the past 20 years he has, with Scott Page, co-directed our Graduate Workshop. The central scientific theme of this program, computational social science, has become a subfield for which Miller is certainly among the world's pioneers.

His success, along with the examples of many other SFI postdocs, belies the founders' early worries that a segue into complexity science could be a career killer. In fact, the Institute's postdocs consistently move into leadership positions in academia, research, and industry.

This trend was bolstered in 2008 with creation of the Omidyar Fellows program that formally seeks to develop what we call the "new leadership for new science." Omidyar Postdoctoral Fellows spend up to three years at SFI where they pursue their own research in complexity science – and take part in a training program structured to develop leadership skills for their residencies and beyond. Although the program's creation was accompanied by the familiar worries about career trajectories that include complexity (what university department would want a young faculty member who had so boldly stepped out of the primary scholarly stream?), those fears again proved to be unfounded. Our Omidyar Fellows have landed on their feet, and many of them already lead major programs in academia and industry. The program's current faculty director is John Miller.

Often we were approached by **young scholars eager to be involved with SFI's new science,** and we realized we needed to figure out a way to accommodate them. And we did so, often informally.

Miller came to SFI though our social network. Our first undergraduate fellow, Julie Rehmeyer, just knocked on the door. "When I was sixteen years old in 1988, I wandered down the hill from St. John's College to a convent on Canyon Road," she writes. "I'd heard that the Santa Fe Institute was housed in it, and although I didn't quite know what people did there, I'd heard that it involved interesting math and science and I wanted to be part of it. I asked Mike Simmons, the vice president, if I might become an undergraduate intern. 'What a great idea,' he said. 'We'll start an undergraduate internship program!'"

That Eureka moment didn't immediately play out, but Rehmeyer gets it essentially right: often we were approached by young scholars eager to be involved with SFI's new science, and we realized we needed to figure out a way to accommodate them. And we did so, often informally.

In 1992 we successfully applied for National Science Foundation (NSF) funding and ever since have supported summer undergraduate research – usually with about a dozen students in residence. Students work with an SFI mentor on

a mutually determined research project that often results in publication. For her part, Rehmeyer pursued several such research projects at SFI, went on to study applied mathematics, and became a well-known science writer; in January 2014 she returned as an SFI Journalism Fellow.

Thus, by 1988 – within two years of opening our doors – we had established what would become the backbone of SFI's educational outreach. Over the next decade we would tweak the schools and residential programs to include international events, student workshops on special topics, and fellowship opportunities for graduate students and high school participants. Tuition-free, education funding was sourced from external grants and unrestricted SFI monies. Promotion and recruitment got more sophisticated, and word of mouth worked in our favor.

Meanwhile new digital technologies were emerging that would impact us. At MIT's Media Lab, Mitch Resnick's group built StarLogo, a programmable modeling environment for exploring the workings of decentralized complex systems. StarLogo's programming language is accessible to middle and elementary schoolers without advanced mathematical or programming skills. Suddenly a door to reaching younger students opened. Here were the 21st century citizens whom the founders dreamed of reaching with the complexity paradigm.

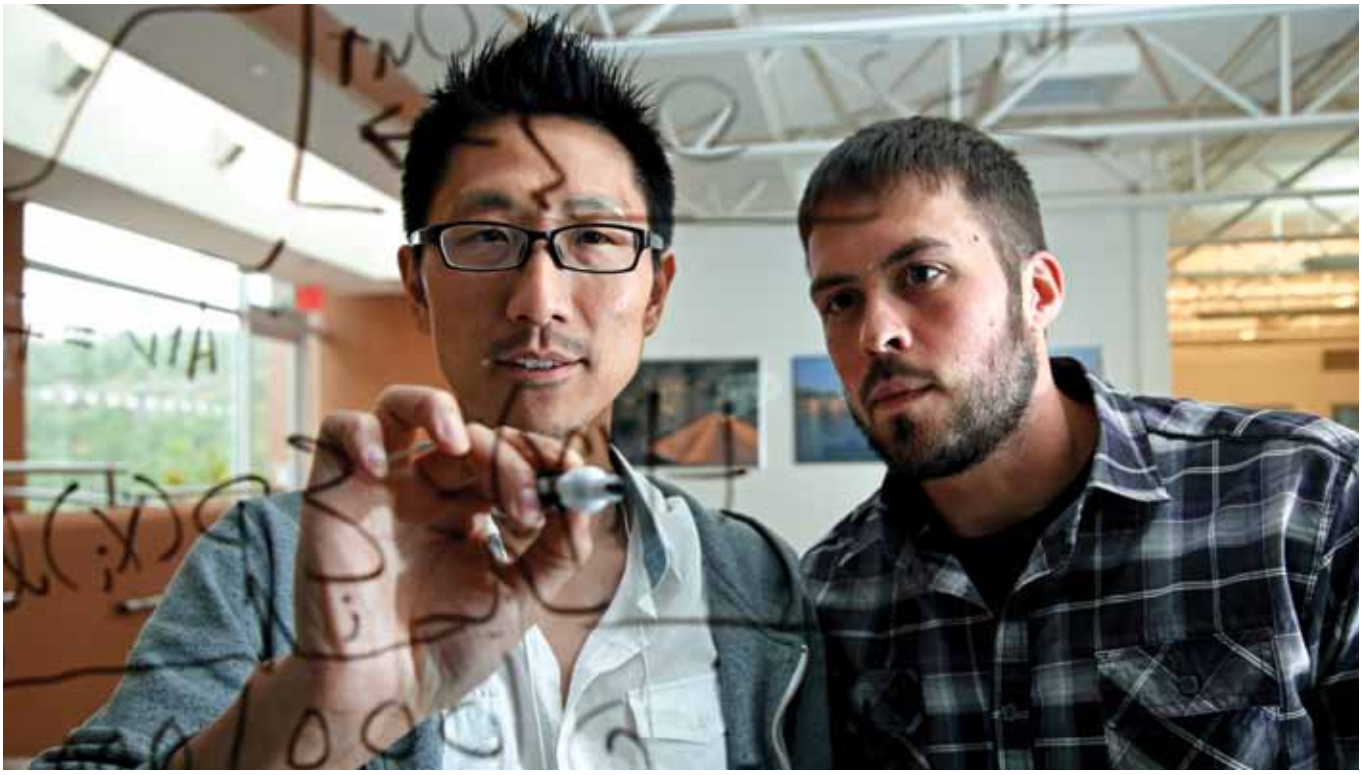
Here, too, was an unexpected opportunity to add a youth component to the SFI program. In 1999 one of Resnick's students, Eric Klopfer, visited SFI as an NSF Postdoctoral Fellow researching teacher professional development using computer simulations. Klopfer and Irene Lee – a member of the SFI spinoff Swarm Development Group, game developer, and science education specialist – launched a series of "Adventures in Modeling" workshops to explore how to best bring new complex systems content and teaching practices to middle and secondary schools. Funded by the NSF, these workshops explored different formats over the next decade and ultimately launched Project GUTS: Growing Up Thinking Scientifically. This afterschool program introduces middle school students to computer modeling and complex systems using the students' schools and neighborhoods as the context for science inquiry. There are now 30 GUTS clubs in New Mexico, and the nonprofit code.org is in the process of taking the program to schools nationwide.

Suddenly **a door to reaching younger students** opened. Here were the 21st century citizens whom the founders dreamed of reaching with the **complexity paradigm.**

In 2012, the Institute expanded on the GUTS initiative to create the SFI Learning Laboratory, with Lee as its director. The Lab researches best practices in teaching complexity science, evaluates current education efforts, and creates new models for complex systems education. It is complemented by the Complexity Explorer (complexityexplorer.org), an SFI-curated website that provides online courses and other educational materials related to complex systems science.

The Explorer completes a continuum, of sorts: today, a complex systems learner can step through Institute-sponsored activities ranging from middle school to adult career development, or they can enter them at any point in their education journey. Every year hundreds of participants do so.

Hundreds is a good number, but thousands



SFI ARCHIVES

SFI's signature education program, the Complex Systems Summer School, provides graduate students and postdocs an intensive four-week introduction to complex behavior in mathematical, physical, living, and social systems in Santa Fe.

would be better. Our growing reputation fills our schools and residencies, but face-to-face educational experiences are ultimately limited. Course schedules are routine but episodic. SFI's campus is spectacular, but it offers no classrooms or residential facilities.

Once again digital innovation has changed the game, this time with MOOCs (massive open online courses). In 2013 Melanie Mitchell taught the Institute's first MOOC. The 16-week "Introduction to Complexity" drew more than 7,000 students. It marked the debut of a growing series of free online SFI courses designed to cover a range of complexity science topics and to appeal to students at variety of levels. Since this inaugural, introductory MOOC, we've rolled out three more courses (offered throughout the year), each of which has garnered several thousand students. MOOCs probably will not replace the Institute's on-campus courses, but they may prove to be transformational. Already they have struck down the historical barrier between SFI and its potential global student body. A campus has become less relevant.

We're not a traditional university, so virtual courses won't siphon students off our campus. MOOCs may indeed bring students to us. Onsite schools and fellowships could become capstone experiences rounding out preliminary online study. Our MOOCs are already required introductory material for CSSS and undergrad fellowships. They will likely also drive more flipped formats (lectures online/hands-on "homework" exercises in class) across our course spectrum. Ultimately we want to develop a full-scale complexity science certificate program on our MOOC platform.

A canonical business model for online education has yet to emerge, but a definite requirement for SFI's MOOC courses will be financial sustainability. In 2011 the education program ceased to be supported by internal funds. Fortunately, we were able to transition successfully from underwritten support to tuition-based programs without losing enrollment or diluting student quality. All direct education costs are now covered

SFI ARCHIVES

GUTS y Girls is a science, technology, math, and engineering program for 6th-8th grade girls in New Mexico. GUTS y Girls features a series of Saturday workshops held once a month and a private online social network where participants interact with each other and professional scientists.

by course tuition, program-specific grant awards, or externally supported scholarship programs. Financial autonomy, now and in the future, will generate program stability as well as backstop experiment and innovation.

A near-term experiment that interests us is how to forge stronger connections between our student bodies and SFI's research as it happens. We're exploring having Learning Lab staff consult with Institute researchers before, not after, they submit research proposals. Collaboration at the pre-proposal stage results in awards that move beyond boilerplate to incorporate meaningful educational outreach that matches content. We also want to actively encourage researchers to produce short, informal MOOCs chronicling their real-time work on specific projects. Not only would this offer a fascinating glimpse into science practice, it would give researchers a chance to hone their teaching and communication skills.

Twenty-six years after George Cowan and Murray Gell-Mann first imagined SFI educational outreach, we're still not a Rockefeller University. Our education program instead is the serendipitous product of both intent and surprise. Yet it has successfully created a unique and robust learning community that we think the founders would find true to their purpose. And just as the founders did in 1984, we look forward to inspiring the next generation of learners and leaders in complexity – in the spirit of their original vision. ◀

Ginger Richardson is the McKinnon Family Vice President for Education and Outreach at the Santa Fe Institute. During her 28-year career at SFI, she has been the driving force and steady hand behind the gradual development of the world's first, and foremost, complex systems education program. SFI's programs now serve learners and teachers from middle school through adult professional education, providing a continuous learning path through all stages of education. She plans to retire from SFI in December 2014.

MINESH BACRANIA PHOTOGRAPHY