Training the next generation of "night scientists"

(Workshop Summary)

Eva-Maria Schoetz[1], Scott Barolo[2], Robert J. Full[3], Onofrio Gigliotta[4], François Grey[5], Eva C. Guinan[6], Jeehyung Lee[7], Ariel Lindner[8], R. Beau Lotto[9], Dusan Misevic[8], Thomas E. Murphy[10], Joseph J. Niemela[11], Zoran Popovic[12], Livio Riboli-Sasco[8], Ingmar Riedel-Kruse[13], Michael F. Schatz[14], Thomas Schaus[15], Mark D. Shattuck[16], Kenneth Showalter[17], Kenneth O. Stanley[18], Harry L. Swinney[19], Luping Xu[8], and François Taddei[8,*]

[1] 170 Carl Icahn Laboratory, Lewis-Sigler Institute, Princeton University, Princeton, NJ 08544, USA
[2] Department of Cell and Developmental Biology, University of Michigan Medical School, Ann Arbor, MI 48109-2200, USA.
[3] Department of Integrative Biology, University of California, Berkeley, CA 94720-3140, USA
[4] Natural and Artificial Cognition Laboratory, University of Naples Federico II and ISTC-CNR, Napoli, Italy
[5] Citizen Cyberscience Centre, CERN, Geneva, Switzerland
[6] Pediatric Oncology, Dana-Farber Cancer Institute, Boston, MA 02115, USA
[7] Department of Computerscience, Carnegie Mellon University, Pittsburgh, PA 15213, USA
[8] INSERM U1001, University Paris Descartes, Sorbonne Paris Cité, Centre for Research and Interdisciplinarity (CRI), Paris, France
[9] Lottolab studio, University College London, London, UK
[10] Department of Electrical and Computer Engineering, University of Maryland, College Park, MD 20742, USA
[11] Abdus Salam International Centre for Theoretical Physics, Trieste, Italy
[12] Center for Game Science, University of Washington, Seattle, WA 98195-2350, USA
[13] Department of Bioengineering, Stanford University Stanford, CA 94305-5125, USA
[14] School of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332-0430, USA
[15] Wyss Institute for Biologically Inspired Engineering, Harvard University, Boston, MA 02115, USA
[16] Benjamin Levich Institute and Physics Department, The City College of New York, New York, NY 10031-9198, USA
[17] C. Eugene Bennett Department of Chemistry, West Virginia University, Morgantown, WV 26506-6045, USA
[18] Department of Electrical Engineering and Computer Science, University of Central Florida, Orlando FL 32816, USA
[19] Center for Nonlinear Dynamics, University of Texas at Austin, Austin, TX 78712, USA

*To whom correspondence should be addressed. Email: taddei.francois@gmail.com

"Night science wanders blind. It hesitates, stumbles, recoils, sweats, wakes with a start.

Doubting everything, it is forever trying to find itself, question itself, pull itself back together.

Night science is a sort of workshop of the possible where what will become the building material

of science is worked out."

—François Jacob, *Of Flies, Mice and Men*

Learning science by engaging in actual research provides not only the classical scientific knowledge produced by what François Jacob called **day science** (*1*), but also the thrill of **night science**, which only the exploration of the unknown can provide. Unfortunately, too few people around the world have access to such experiences. In the last few years, different initiatives have emerged promoting inexpensive and practical hands-on experiments that are inexpensive and easy to realize, "citizen science", crowd sourcing of research, and scientific discovery games. These innovative educational practices make science accessible to many people outside the traditional science training pipeline, and allow even the youngest children to contribute to scientific research.

    In an attempt to bring together those who innovate along these lines of science education, the Center for Research and Interdisciplinarity (CRI), which was initiated by two of the authors (F.T. and A.L.) in 2005 in Paris Descartes University and is funded by the Bettencourt Schueller Foundation, invited about 30 international innovators in science education to Paris this summer, to look for synergies between their teaching approaches and online and real life activities to generate new ideas for accessible science education. The CRI was an ideal setting for this workshop, as learning through research is at the core of its unconventional undergrad, master and PhD interdisciplinary programs, which includes student-run outreach activities that allow high-school students from disadvantaged areas to experience scientific research (*2*). This program, which has recently been scaled up to the national level, serves as an example of the

application of scientific culture to social issues (*3-4*).

Hands-on Experiments

Modern science sometimes requires large facilities (e.g., the Large Hadron Collider, the Hubble Space Telescope), which attract the attention of scientific and popular media, contributing to and reinforcing a common misconception that *all* modern experimental science necessarily involves expensive instrumentation and infrastructure. Hands-on Research Schools (http://handsonresearch.org), co-founded by keynote speaker H. Swinney, provide counterexamples that demonstrate how inexpensive table-top science can address cutting-edge scientific questions. School Co-director K. Showalter explained that the centerpiece of the schools, which are designed for early-career scientists from developing countries, is daily laboratory sessions on chemical, physical, and biological problems as published in leading scientific journals, *e.g.* (*5-7*). Participants learn to exploit inexpensive consumer hardware such as web cameras and the open source Arduino microcontroller, illustrated by T. E. Murphy, to address problems at the frontiers of science. E.-M. Schoetz emphasized that many biological problems are well-suited for a table-top approach and are readily adapted to address important problems of local interest, such as *Schistosoma mansoni* in a previous school in Africa. M. D. Shattuck gave examples of training sessions for the participants to develop mathematical modeling and data analysis skills using software such as MATLAB, which is widely used in industry and academia. M. Schatz leads sessions for undergraduate and high school students, showing how interactive engagement methods enrich critical thinking skills, while Schoetz is developing an initiative to engage high school girls in Cameroon in hands-on activities. The Hands-On Research Schools have been sponsored since their inception in 2008 by the UNESCO-administered Abdus Salam International Centre for Theoretical Physics (ICTP; www.ictp.it) in Trieste, Italy. J. Niemela elaborated how these schools are a new component in

the ICTP portfolio, which includes more than 60 science and education workshops annually, involving more than 6000 participants, with more than half from developing countries.

Citizen Science and Crowdsourcing of Research

Today, we face a fast-evolving and often unpredictable landscape that requires new learning and research strategies. Using analogies to chess champion Gary Kasparov's experiences with man-computer collaborative and "crowdsourcing" chess, workshop host F. Taddei emphasized that integrating technology and citizen science to create new learning ecosystems is necessary to allow new generations of students become engaged and critically thinking citizens able to tackle the multifaceted 21st century challenges.

E. C. Guinan discussed crowdsourcing as a means to boost innovation in academic biomedical research programs. She showed that significant improvements, covering an unexpectedly broad spectrum of possible effective solutions, could be provided by non-scientists, and that many of them could be realized rapidly and cheaply. The Citizen Cyberscience Centre, coordinated by F. Grey and supported by the Shuttleworth Foundation, also engages citizens in contributing new research ideas, especially for humanitarian projects in developing countries. Concrete examples include the Computing for Clean Water project, which helps scientists to design efficient low-cost water filters for clean water, and UNOSAT, which encourages citizens to help improve damage assessment data for Libyan cities by geotagging Web images of damaged buildings.

K. O. Stanley and O. Gigliotta showed two different approaches of teaching evolution and natural selection as well as engaging the public directly in evolution research. Stanley introduced the program Picbreeder (*8*), which allows web users to collaboratively evolve images over many generations, echoing the process of natural selection, while Gigliotta and colleagues combined a computer game, BreedBot (*9*), which allows users to breed a population of

simulated robots under natural or artificial selection, with the goal of testing the evolved controller on real robots. R. J. Full and R. B. Lotto closed this session with examples of their outreach work involving school kids. Full discussed about his contributions to the Kids Science Challenge (kidssciencechallenge.com), a USA-nationwide competition in which 3rd to 6th graders to submit experiments and scientific problems, which are then solved by professional researchers. Lotto, whose lab is located in the Science Museum in London, co-authored a peer-reviewed paper with schoolchildren aged eight to ten, who described in their own words their experiments testing bees' ability to recognize color patterns and spatial characteristics (*10*).

Scientific Discovery and Adaptive Learning through Games

Games, according to keynote speaker Z. Popovic, are perhaps the ideal framework for creating a symbiotic human-computer problem-solving architecture for solving scientific and educational problems. Popovic also emphasized the importance of games to improve science education, particularly in basic mathematics and physics. The need for an improvement of basic science education at high schools is currently also a focus of the National Academy of Sciences, which released a book earlier this year, entitled *Learning Science Through Computer Games and Simulations (11)*. Using the protein folding game *Foldit* as a concrete example, Popovic described efforts towards scientific discovery games that use multiple methods of engagement to evolve novice citizens into state-of-the-art researchers (*12*). Another example of that kind was provided by J. Lee: *EteRNA*, an online RNA design game, created by Stanford and Carnegie Mellon, is unique in integrating high-throughput biochemistry. Lee presented data showing that the player community outperformed the best computer algorithms in the field, and argued that citizens can contribute to scientific progress by presenting their creativity and intuition in a structured form.

T. Schaus and I. Riedel-Kruse built the bridge from virtual games to real games: Schaus

and his mentor P. Yin at Harvard University, in collaboration with F. Taddei, P. Marchal, A. Lindner, D. Misevic and L. Xu (CRI), are developing a game in which students play with simulated DNA structures on a computer and then recapitulate their exploration in a hands-on way with actual "magnetic bases" mimicking DNA-origamis. Riedel-Kruse's "biotic games" allow a human player to interact in real time with live biological systems, such as single celled Paramecia in an electric field, to play a Pac-Man-like game (*13*). Biotic games to solve scientific and educational challenges are at the heart of the new Stanford Bio.X games center, cofounded by Riedel-Kruse.

Finally, S. Barolo demonstrated how the game of Mastermind, a simple logic game in which the goal is to break a secret code using repeated rounds of experiment-result-interpretation-design, can be used to reinforce scientific concepts such as the importance of controls, the power of negative data, and the dangers of over-interpreting one's results (*14*).

Workshop Initiatives

This workshop brought together a group of innovators who have independently introduced novel concepts in science education. To achieve a global impact, we must combine our ideas and resources to create a network of people developing innovative learning ecosystems. The following initiatives for a science "co-opetition" and a science wiki-website, developed collaboratively at the Paris workshop, will allow everybody who is passionate about science and education to engage in ***night science***.

Night science co-opetition

We are launching an international contest of new ideas for engaging citizens in scientific research (www.nightscience.org). Teams of participants, working with the guidance of a professional scientist, can either accept a targeted challenge proposed by the organizers or

propose their own project in one of three open categories: (1) Learning by playing: teams are invited to propose new scientific discovery games that allow players to contribute to research, (2) Learning by doing: teams can propose new hands-on experiments that are cheap to perform and relevant scientifically, (3) Learning by questioning: teams are invited to propose new "Socratic technologies"; the challenge here is to invent technologies that can foster learning via the Socratic method.

The spirit of the contest is *open source*, i.e., all ideas proposed by participants will be disseminated under a Creative Commons license to allow anyone to share, and further develop ideas for the benefit of all. Another important dimension of the contest is described by the term "co-opetition," which describes a competitive-collaborative hybrid and means that everyone is encouraged to build on and improve the ideas of others. Every team will document their progress on a wiki page, and all participants can contribute to the ideas they find the most relevant. During the co-opetition, participants will be able to get help from professional scientists, and the contest winners will be offered an opportunity to develop their ideas further in one of the leading labs in the world.

Web resource initiative

The workshop participants will collaboratively launch a website that covers a comprehensive spectrum of education resources, from low-cost table-top experiments, freeware programs, educational games, lecture demos, and science blogs, to interesting homework assignments, free online textbooks/courses, relevant papers published in Science education page and links to other education websites and funding opportunities. While these categories are broad, they can all be thought of as individual, unique "teaching (and/or) science nuggets". They should represent the most fun, successful, inspired and inspiring, spark-inducing, love-for-science

generating moments from educators' careers; moments they would have wanted to experience when they were students, and the ones they would hope for their children to experience in the classrooms of today and tomorrow.

Although many of these topics are served by existing online sites, to our knowledge there is no single resource that covers them all—a kind of Wikipedia of science education. Our plan is to fill this gap and create a website that provides educators at all levels with a toolkit for cutting-edge science education, something that is especially lacking in developing countries. This website is clearly a grand challenge and cannot be created, maintained, and updated by only a few individuals, thus it must become a community-driven project with content created and uploaded by users. We are designing the site to be a highly cross-referenced, easily searchable database, in which novel educational techniques will be tested and evaluated by the worldwide science education community.

Celebrating the 50th anniversary of the "operon" this year, Francois Jacob, in a recent *Science* essay (*15*), reinforced his belief that the world needs more ***night science*** to make scientific progress. The two global initiatives that were launched at this workshop aspire to inspire everybody – independent of age or geographic origin - to dare take on the adventure of becoming true ***night scientists***.

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