What we don’t know, we teach one another

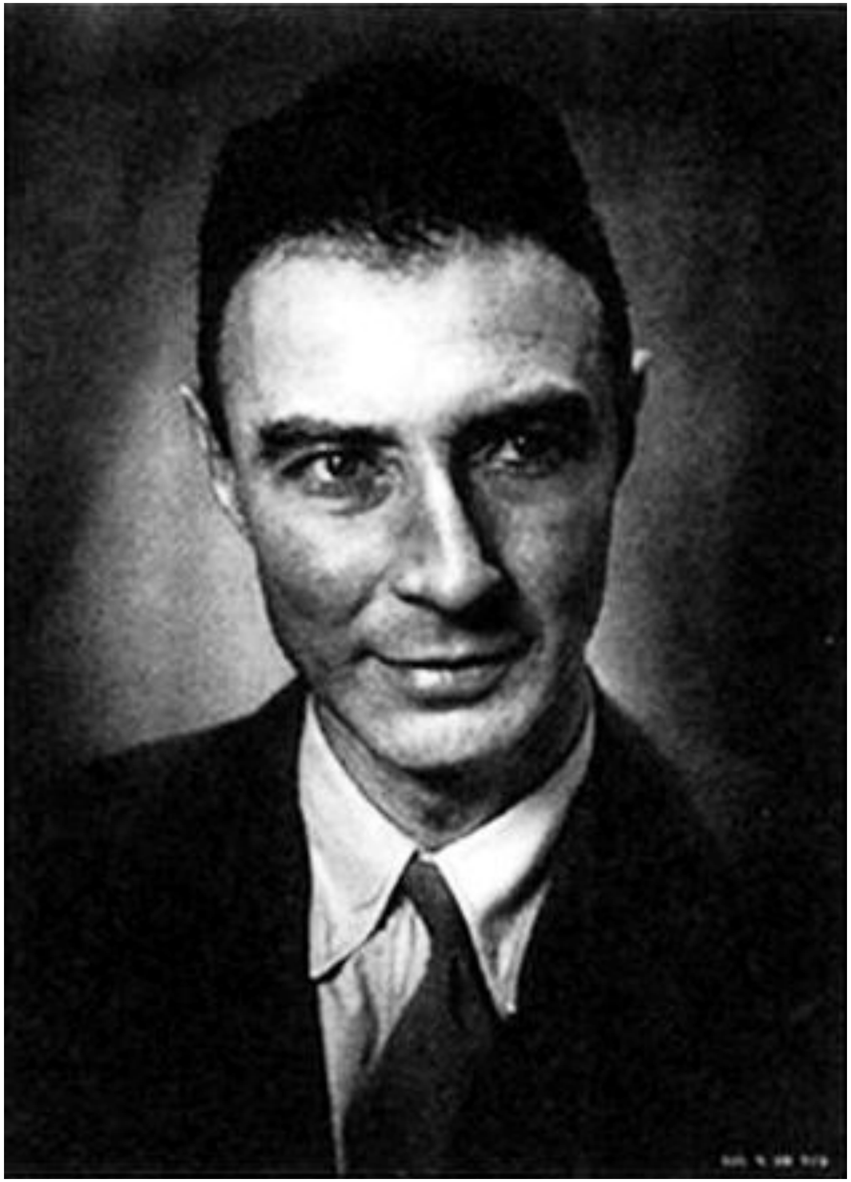
Robert Oppenheimer , describing the profession of theoretical physics, in 1946

My Undergraduate Teachers

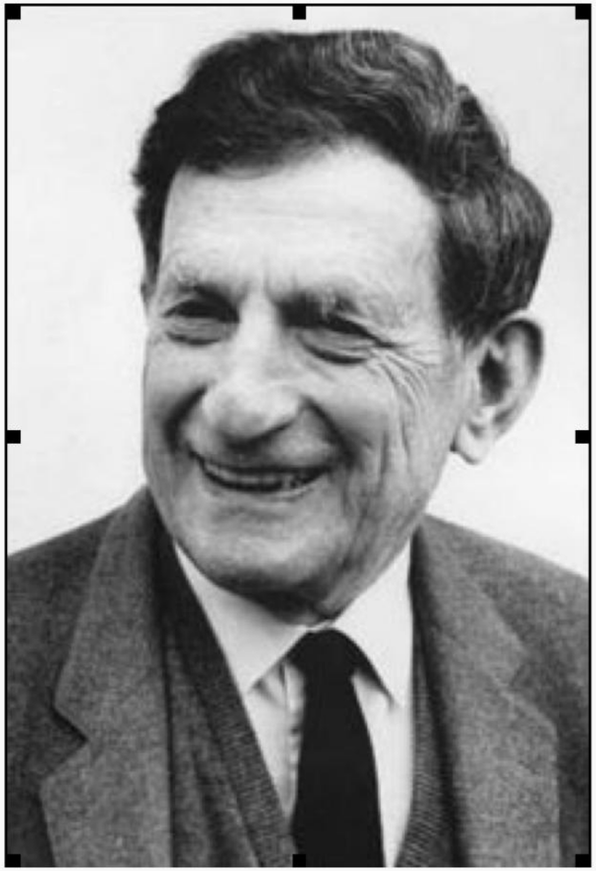
- **1940-41 Black Mountain College Nathan Rosen taught me calculus and suggested I might become a theoretical physicist**
- **1941-44 UC Berkeley Joe Weinberg introduced me to quantum theory and Robert Oppenheimer in 1943**

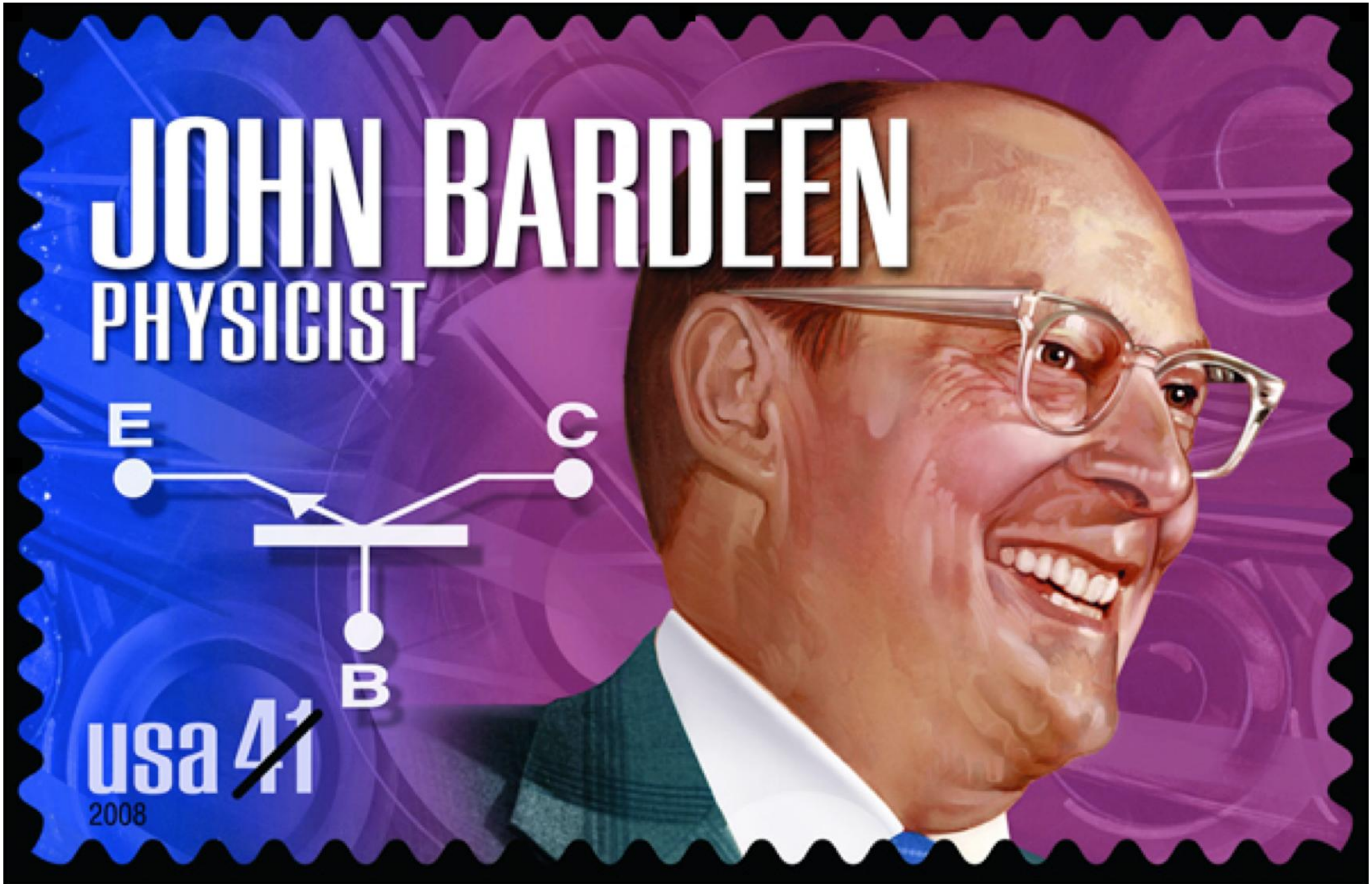
My Mentors

- **1946-47 UC Berkeley Robert Oppenheimer [Opje] taught me quantum mechanics, inspired and encouraged me to become a theorist, and became a close friend as I followed him to Princeton.**
- **1947-50 Princeton University David Bohm gave me a great thesis topic, was my office-mate from 1948-50, and was a friend, collaborator, and correspondent during 1950-53.**
- **1952-54 University of Illinois   John Bardeen was my postdoctoral mentor and office-mate who became a close colleague and close friend there from 1959-1991.**



David Bohm




JOHN BARDEEN
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What I learned from Oppenheimer and Bohm was the importance in teaching, writing, and research of focusing on fundamental ideas and experiments, not equations, an approach that was reinforced by John Bardeen, with whom I shared an office as his first postdoc during the period 1952-55, and whose office was adjacent to mine from 1959-1991 after I joined the UIUC faculty.

John also taught me the importance, in working on a truly difficult problem, of focusing on experiment, and developing a phenomenological understanding of the key experimental results, before attempting to propose and solve a microscopic model to explain these, a strategy I have endeavored to follow my own research and to communicate in my subsequent books and lectures.

1955-57 From January, 1955 to June, 1957 I was teaching at Princeton. A talented young graduate student, Philippe Nozieres came from France on a Princeton fellowship from France to work with me there. Thus began our interaction [we learn so much from our students] that began with his PhD thesis on electron interaction in solids and led during the following decade to a most fruitful research and book collaboration

1957-59 Bardeen, Cooper, and Schrieffer developed the microscopic theory of superconductivity in the spring of 1957 and the many-body problem, in which one sought common features in electron and nuclear matter and liquid helium, emerged as a distinct subfield of physics.

From June, 1957, to September, 1958, I was in Europe [Copenhagen, Varenna, Paris, and Les Houches] where I lectured on BCS and applied it to nuclear matter and nuclei; I spent the academic year, 1958-59 at the Institute for Advanced Study, where I worked mainly on superfluid He and lectured on BCS and the many-body problem before I began my long-term service on the Illinois faculty in the fall of 1959.

Frontiers in Physics was conceived in the fall of 1960, during a visit to my office in Urbana by Bill Benjamin, who was seeking authors for his just-beginning company, W.A.Benjamin.

I told him what we really needed were not new textbooks on
standard topics, but ways to bring frontier topics in physics to a broad audience, through notes written by the lecturers or their students, such as those I had prepared for my lectures on “The Many-Body Problem” during the past few years.

Bill liked the idea, I agreed to edit the series, and Frontiers in Physics emerged as a Benjamin series in 1961

I knew FIP would be a success when, during the APS meeting in NYC in January, 1961, after I had described the concept to Freeman Dyson and Dick Feynman, Freeman turned to Dick and said he had to be part of the experiment.

Dick agreed. Two Feynman volumes were among the inaugural volumes for FIP, and another five books based on his lectures appeared subsequently in the series.

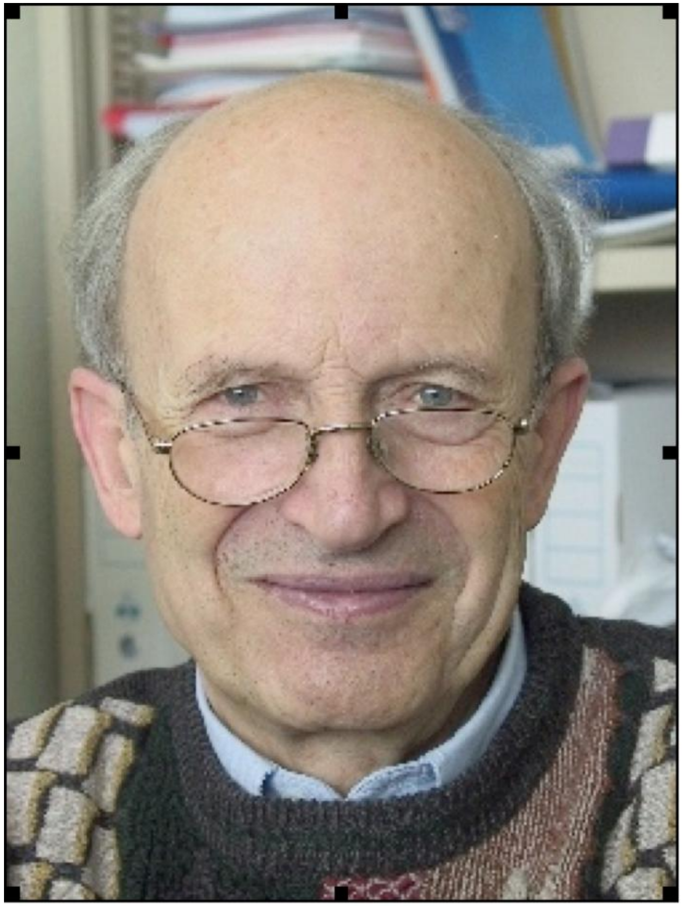
Here are the initial 7 of the 104 "Frontiers" volumes:

N.Bloembergen Nuclear Magnetic Relaxation
Geoffrey F. Chew S Matrix Theory of Strong Interactions
R.P.Feynman Quantum Electrodynamics
R.P.Feynman The Theory of Fundamental Processes
H.Frauenfelder The Mossbauer Effect
D.Pines The Many Body Problem
L.van Hove, N.Hugenholtz, L.P.Howland Problems in the Quantum Theory of Many Particle Systems

The genesis of “The Theory of Quantum Liquids”.

1961 Nozieres and I began corresponding about writing a book on quantum liquids; I obtained a year’s leave of absence from Illinois to work again with him in Paris at the Ecole Normale and teach at Orsay during the academic year,1962-63.

1962 The following summer, sitting on the beach in front of the Hotel Thalassa, during breaks from the 1962 Cargese Summer School on the Many Body Problem I had organized, we decided on our approach and put together our first outline



Planning the Theory of Quantum Liquids

We decided our audience would be experimentally-inclined graduate students for whom we should focus on the physical ideas and basic concepts involved in understanding quantum liquids—quasiparticles, collective modes, response functions, sum rules…—and that we would employ a minimum of formalism and no Feynman diagrams.

We sketched out two volumes:

Vol. 1 Fermi liquid theory, metallic electrons, and liquid Helium3

Vol. 2 Bose liquid theory, Superfluid Helium 4, and Superconductivity

Working mainly in Paris, we finished Vol. 1 and the first part of Vol.2--that dealing with Bose liquid theory and Superfluid Helium 4—by the fall of 1964.

Vol. 1 was published in early 1966.

Vol. 2 in its original form was set aside, because the many new developments in superconductivity, coupled with our unwillingness to commit another two years to our planned volume, brought to an end our plans to write about superconductivity.

Twenty-five years later, we were persuaded that despite the passage of so much time since the manuscript was written, it might still be useful to make that first part of Vol. 2 available to a broad audience; it was published [with no changes from the 1964 version] in 1989.

That both volumes are still being read is due in large part to our decision to focus on the basic physics; while applications evolve over time, the underlying fundamental physics does not.

Some further, and much more recent, experiments in education

During the past decade, I have became increasingly engaged with experiments designed for a different audience—one that ranges from undergraduates and their teachers, high school teachers, and the scientifically curious public, to internet savvy high school students and middle school teachers. I'd like to share four of these with you:

***Building an online multimedia course around a new paradigm**
***Developing a new trans-disciplinary course at UC Davis**
***Supporting online exhibits and an online science museum**
***Founding global institutions and developing new partnerships**

Writing for an online audience

"Physics for the Twenty-first Century" is one of a series of online multimedia courses and modules supported by the Annenberg Foundation that are aimed at high school teachers and undergraduates—for a listing of these teacher resources
go to
http://www.learner.org/resources/browse.html?discipline=6&grade=0.

In the unit I wrote and coordinated,
Emergent Behavior in Quantum Matter,
the viewer is introduced to the challenge and excitement of research at the frontiers of quantum matter through the lens of the emergent behavior we find there.

If you go to http://physics.digitalgizmo.com/courses/physics/unit/text.html?unit=8&secNum=0 you will find both old wine in new bottles and new wine:

Emergent Behavior in Crystalline Solids
Emergent Behavior in the Helium Liquids
Gateways to a Theory of Superconductivity
The BCS Theory
New Superconductors
Emergent Behavior in the Cuprate Superconductors
Superfluidity on a Cosmic Scale

The unit is built around the major paradigm shift we are now witnessing in science—

The shift from reductionism and a focus on individual components to an emergent perspective involving a focus on the collective emergent behavior of the system as a whole

In the accompanying materials that include videotaped interviews with Piers Coleman and Paul Chaikin, the theme of emergence is taken up in a number of ways

What is emergence?

Emergence is a bulk property. When we bring together the component parts of any system, be it people in a society or matter in bulk, the behavior of the whole is very different from that of its parts, and we call the resulting behavior *emergent*.

More turns out to be not only different [as P.W. Anderson emphasized in his seminal 1972 Science article], but unpredictable from a knowledge of its component parts and their interactions

It follows that we need to rethink reductionism* as the fundamental paradigm for understanding phenomena in science or in society

*according to Wikipedia, reductionism can either mean (a) an approach to understand the nature of complex things by reducing them to the interactions of their parts, or to simpler or more fundamental things or (b) a philosophical position that a complex system is nothing but the sum of its parts, and that an account of it can be reduced to accounts of individual constituents

We live in an emergent universe!

To understand our emergent universe, we must replace the traditional reductionist approach, with its focus on using the individual components as basic building blocks, by an *emergent perspective*, in which our focus is on characterizing collective emergent behavior and searching for the collective organizing concepts and principles that bring it about.

These *gateways to emergence* are the new basic building blocks we must use to understand quantum matter or living matter, the cosmos, ourselves, or the societies in which we live.

Emergence is further examined in Bob Austin's unit, http://physics.digitalgizmo.com/courses/physics/unit/text.html?unit=9&secNum=0, as the viewer learns how to bring principles of physics to bear on the most complex system of them all: living matter

"Physics for the Twenty-first Century" made its online debut in 2010. According to google analytics, from Sept.3-Dec.5, 2012, it received 64,245 page views with an average view being nearly two minutes. Annenberg has provided more than 5,000 video preview DVD's to teachers, and it is our hope that both numbers will increase as many of you now visit the site. Do send your feedback to Annenberg or to me [david.pines@gmail.org]

Online Introductions to Emergent Behavior in Matter

I turn next to two more modest, and considerably less well-financed [when measured on the Annenberg scale] experiments in engagement that have been primarily supported by ICAM, a virtual institute for which I served as Founding Director from 1999-2012, about which I will have more to say later:

http://Musicofthequantum.org

http://emergentuniverse.org

Intended for teachers, students, and internet-savvy individuals aged 18 to 35, these experiments represent steps toward building an online science museum devoted to emergent behavior in quantum and living matter.

http:///musicofthequantum.org was conceived
and implemented by Piers Coleman in connection
with a 2003 ICAM Workshop on"Quantum Criticality" at Columbia University

The site contains a videotape of the 2003 world
Premiere during that workshop of "Music of the
Quantum", a musical composition written by Jaz
Coleman; its three movements are entitled:

Emergence and Broken Symmetry
Transition and Criticality
The Quantum.

At musicofthequantum.org the viewer will also find videotaped interviews with leaders in the study of emergent behavior in matter—Phil Anderson, George Whitesides, Bob Laughlin, Paul Chaikin, Leo Kadanoff, Jerry Gollub, Seamus Davis et al.

Their topics vary from emergent behavior as the new frontier in science to soft matter to quantum criticality and a view of quantum matter using a scanning tunneling microscope.

http://emergent universe.org is an ICAM experiment in building an online science museum.

Its Founding Director, Suzi Tucker, abandoned a highly successful academic career for a career designing museum exhibits. In place are the three wings she designed:

Unlocking the Universe-- exhibits on emergence that contain many examples of striking emergent behavior in science, nature, and society, including an anime comic book, "The Rebels of Complexity", that speaks to the importance of developing an emergent perspective

The Fibril Connection-- exhibits on amyloids, the brain, and the cause and impact of Alzheimer's Disease, that include a dance sequence on Alzheimer's that was composed for the site

Resistance is Futile -- exhibits on superconductivity, the poster child for emergent behavior in quantum matter, that include a flash mob dance sequence illustrating the collective motion of coherent pairs in the superconducting state.

The impact of http://emergentuniverse.org

The reports from google analytics tell us that since its opening, in the fall of 2008, ICAM's virtual museum has had ~100 visits/day. Visitors come from 165 countries. They visit for ~ 4 minutes, view ~ 4 pages; about half come to the site from a google search, a third from referral, and a fifth come from a direct hit.

Since there has been very little direct advertising, I urge each member of my audience to expand these numbers by going to emergentuniverse.org. When you do, please consider how you might be able to make use of its materials in your classes, and send us your feedback-- to the site or to me at david.pines@gmail.com

An emergent trans-disciplinary course

Physics 150: Gateways to Emergence in Science and Society: Toward a Science of Sustainability

Alex Navrotsky and I taught this course during the 2012 winter quarter at UC Davis. Our aim was to provide students with the tools they need to develop an emergent perspective on problems in science and society by focusing on gateways to emergent behavior we have identified in the physical and biological sciences and on gateways that have been proposed for solving some of our major societal problems.

The course was an experiment, stressing interdisciplinary and integrative learning at the upper undergraduate and graduate level. There were several aspects to the experiment: the topic of emergence as a unifying principle bringing together students in different sciences; the emphasis on emergent global problems and the science needed to assure clean, secure, and sustainable energy and food supplies to power and stabilize our world; the integration of high-profile guest lecturers who will also participate in other campus activities; and *grading based on a website created by each student.*

The students judged it a success. You can decide for yourself by going to http://emergence.ucdavis.edu/PHY150/index.html where more information, videotapes of lectures, and the student websites may be found.

A few words about the experimental sponsor of these experiments in engagement

ICAM, the Institute for Complex Adaptive Matter, is an experiment in institution-building

As a global institute, with its home at http://icam-i2cam.org, it supports the study of emergent behavior in matter through a program of fellowships, exploratory workshops, and informal research networks.

Supported by its participating institutions and the NSF, these connect scientists at its 72 branches representing 22 countries and 112 institutions

Importantly, as part of ICAM's effort to bring an understanding of emergent behavior to the general public, it supported musicofthequantum and emergentuniverse.org as well as a series of workshops that continue to bring scientists and informal science educators together to discuss what they might be able do together that they cannot do separately.

Some of the recommendations and talks given at ICAM's recent workshop in this series," Becoming Engaged: Initiatives that can Change Science Education" may be of interest to many of you.

A summary of the workshop and its action agenda may be found at http://icam-i2cam.org/index.php/conferences/detail/becomingengaged/. That site contains as well some not very high quality videotapes of the talks and a description of a proposed new national program aimed at putting graduate students in your classrooms, Engagement Assistants.

Links to descriptions by the participants of some of their initiatives in science education, including major reports prepared by PCAST and the NAS, and a useful definition of science literacy, may be found at the workshop wiki site, http://icam i2cam.org/index.php/conferences/detail/becomingengaged/event_info/

At its 2009 Annual Meeting at the University of Cambridge, ICAM decided to take some first steps toward creating a global educational network by establishing GSEE, the Global Partnership on Science EducationThrough Engagement.

GSEE is another experiment in science education— to see whether by sharing information and working together on major initiatives, a group of leading educational institutions, scientific societies, science museums, corporations, and individuals can accomplish far more than they can by working separately.

GSEE seeks to:

***inspire working scientists to become engaged in informal science education at every stage in their careers, and**

***give them the tools and guidance to do so effectively.**

A brief description of its initial activities and a list of its Founding Partners may be found at http://icam-i2cam.org/index.php/outreach/gsee/.

**During the past year, the number of GSEE Founding Partners has expanded significantly,
with the AAAS, the American Institute of Physics,
Argonne National Laboratory, the National Academy of Sciences, the Field Museum, the Koshland Museum, Northwestern University, MIT, and Fermilab joining ICAM and
17 ICAM branches in becoming Founding Partners.
We hope to be joined shortly by AAPT.**

**In 2013, with the support of the University of Chicago, Kyoto University, the NAS, AIP,Argonne,
and ICAM, GSEE is convening two Founding Summits, GSEE/Chicago and GSEE/Kyoto.**

Participants at GSEE/Chicago and GSEE/Kyoto will:

***Develop regional consortia**

***Explore a path forward to establishing a new journal, "Experiments in Engagement"**

***Explore synergies with other regional and national initiatives in informal science education**

***Plan exploratory workshops on "Experiments in Engagement"**

***Consider how the GSEE online web site, *LearnwithGSEE.org,* might be developed to make the best practices of its GSEE partners readily available to the global educational community.**

What are the frontiers and challenges in engagement that both GSEE and the AAPT might wish to explore? Let me conclude this lecture by suggesting four:

introduce emergence to middle and high school students as a way for them to learn what science is, what scientists do, and the role science can play in their lives and in society

help all our students develop an emergent perspective on their own world and on society at large

enhance appreciably the number of engaged scientists and help them become more effectively engaged in the teaching of science to non-scientists and prospective scientists, beginning with middle and high schools

begin the process of creating a science of engagement

Becoming Engaged:
Science education in middle and high schools

Can we help introduce students to science by teaching them about emergence, providing numerous examples that encourage them to explore their emergent universe?

Can we do this in part by inviting middle school classes to visit our laboratories and by our becoming science ambassadors in their classrooms?

Engaging in science education
in our middle and high schools

Can we develop a middle-school version
of emergentuniverse.org?

Can our goal be to ensure that every student
develops a science-based emergent
perspective on the world around them,
so that as they grow older they could use
that perspective to help solve the problems
they encounter in daily life and as citizens
in the larger society?

Enhancing the number and effectiveness of engaged scientists

Four approaches have been suggested:

Community building-- work individually and collectively to identify and coalesce the community of scientists for whom outreach and public engagement are significant parts of their professional activity

Collaboration—continuing to identify, develop, and communicate effective ways to work with teachers and informal science educators

Culture change-- use our own influence and encourage our colleagues and the institutions and organizations of which we are part to join us in changing the academic culture so that outreach and engagement become valued and respected activities for faculty, and by extension, for post docs, grad students, and undergrads

Convening power--use the convening power of our individual institutions, groups and networks to enhance community building and culture change and to improve and increase our collaborative activities

Can we create a science of engagement?

The recent NAS Sackler colloquium on the Science of Science Communication [http://www.nasonline.org/programs/sackler-colloquia/completed_colloquia/science-communication.html] leads one to ask whether a science of engagement could emerge from the many experiments in engagement being carried out by scientists in this country and abroad.

What are some minimal requirements?

That it be, like any other sub-field of science, experiment-based

Some additional minimal requirements for a science of engagement

Creation of a community of engaged scientists with well-defined mechanisms for arriving at a consensus on what constitutes effective engagement

Development of an online journal, "Experiments in Engagement ", that publishes refereed articles by engaged scientists describing their experiments in engagement-- a first step toward creating a body of knowledge on effective engagement.