Addressing 21st Century Grand Challenges through Interdisciplinary Research and Education-An NSF Perspective

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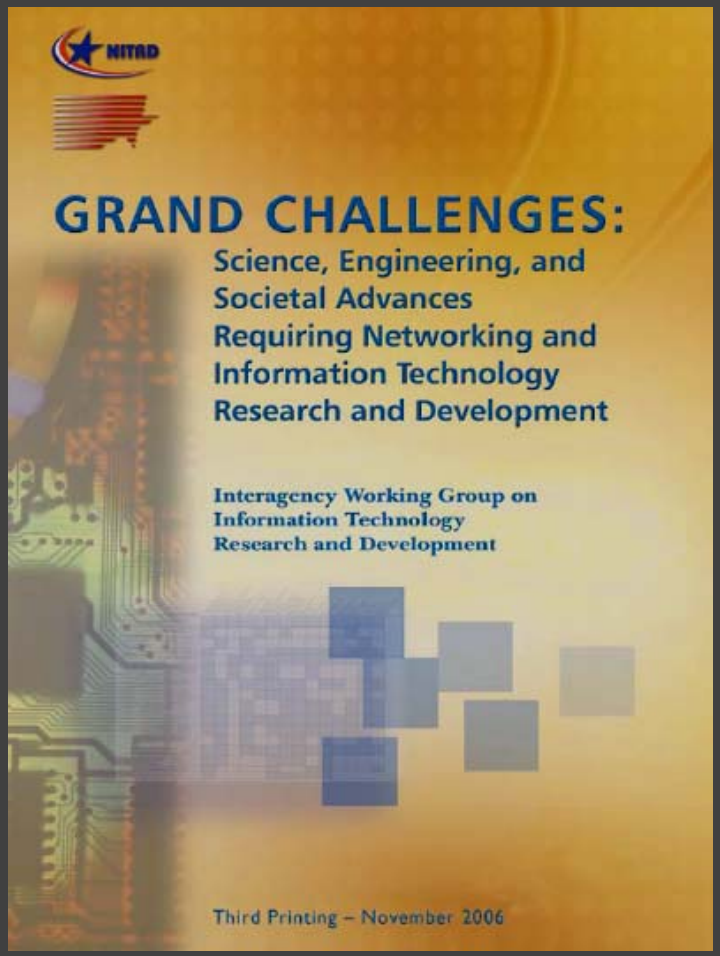
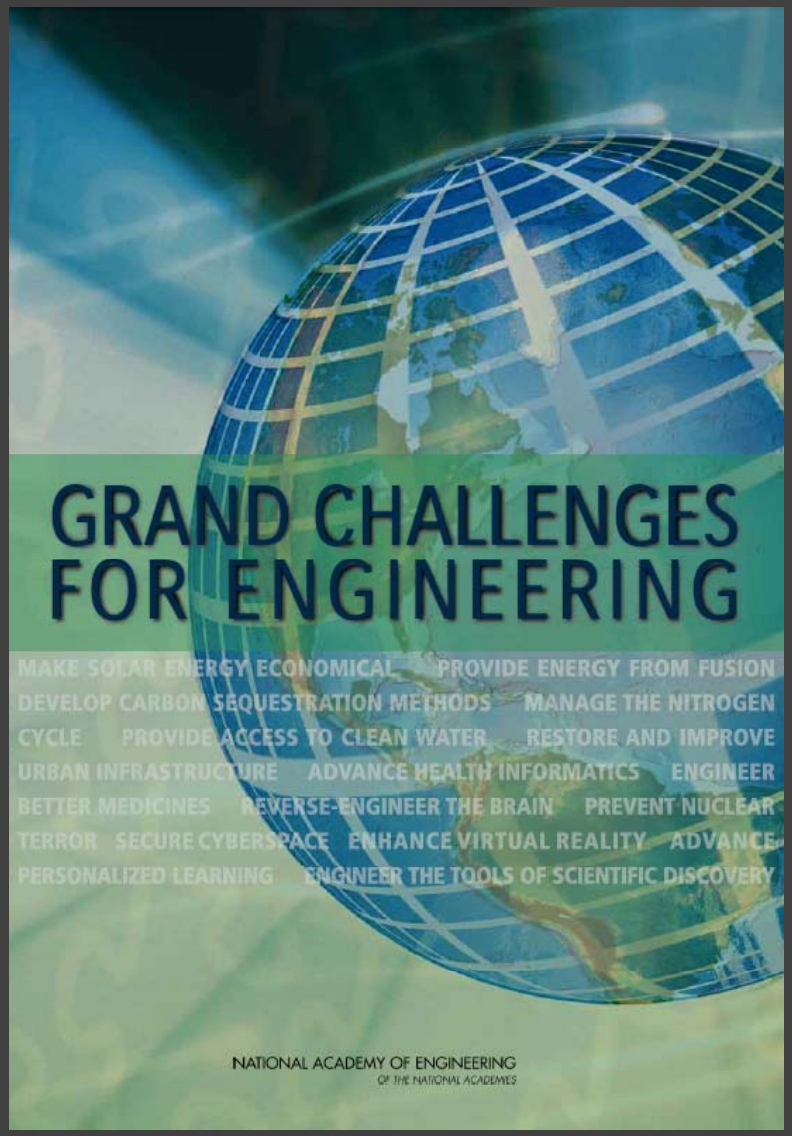
21st Century Grand Challenges

- What are Grand Challenges?
- Grand Challenges are the research themes and questions that have the greatest potential to advance STEM disciplines and to promote human wellness and sustainability.
- Several professional societies, think tanks, and government organizations over the past decade have identified some of the 21st century Grand Challenges for STEM fields.


DOE/SC-0135
Grand Challenges for Biological and Environmental Research: A Long-Term Vision
A Report from the Biological and Environmental Research Advisory Committee

DOE, 2010


NITRD
GRAND CHALLENGES:
Science, Engineering, and Societal Advances Requiring Networking and Information Technology Research and Development
Interagency Working Group on Information Technology Research and Development
Third Printing – November 2006



2008

A NEW BIOLOGY FOR THE 21ST CENTURY

Committee on a New Biology for the 21st Century:
Ensuring the United States Leads the Coming Biology Revolution

Board on Life Sciences

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

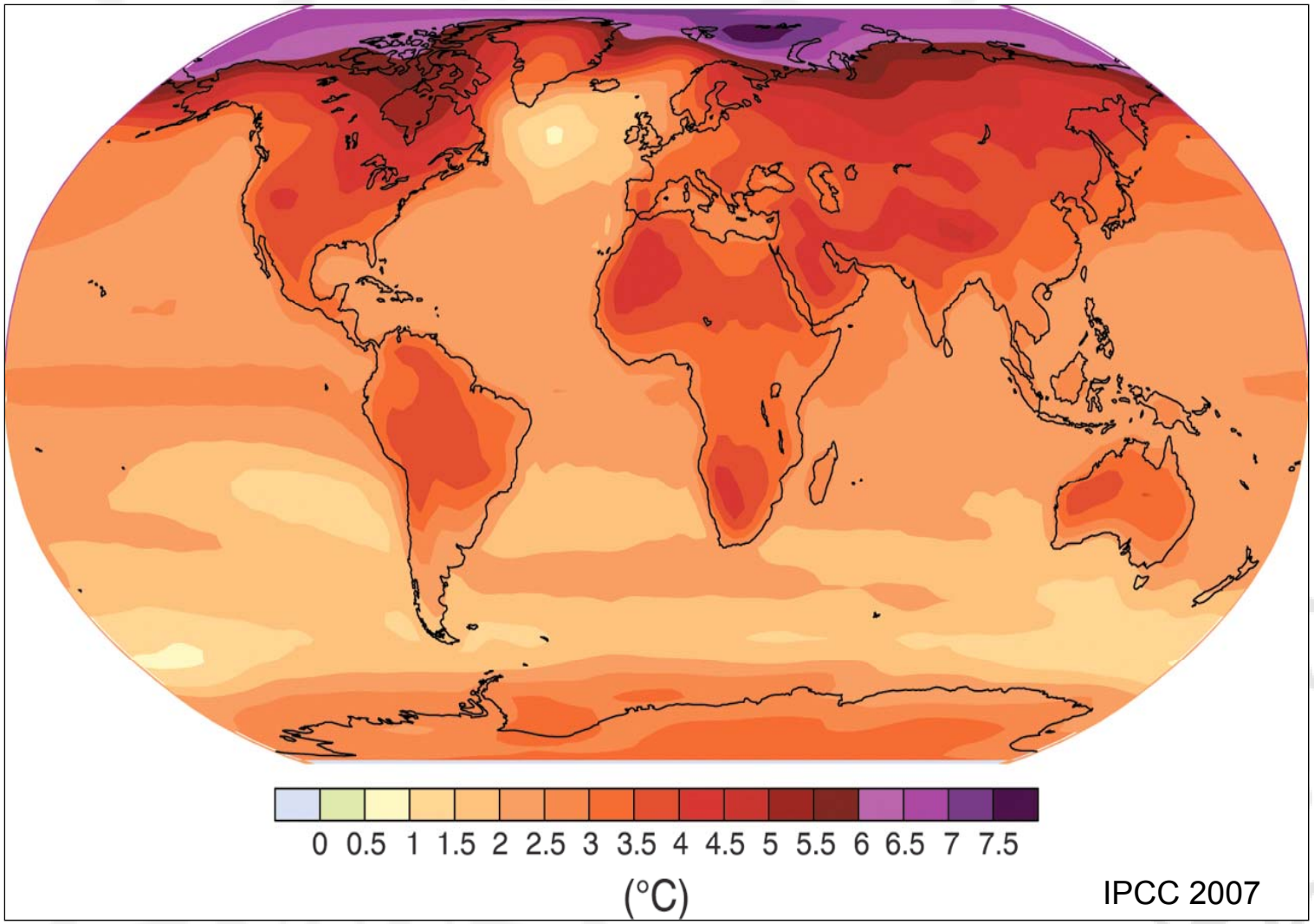
THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

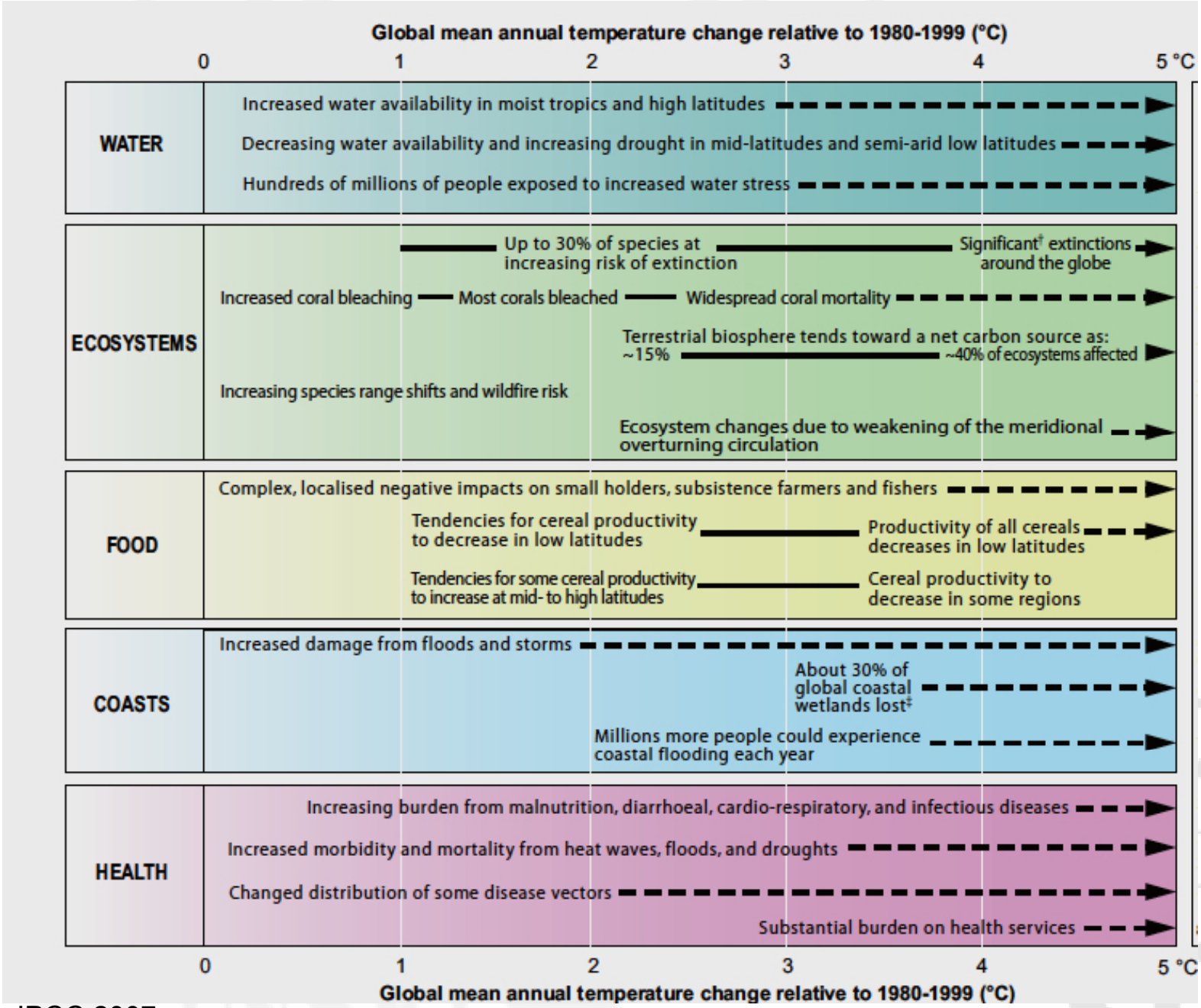
2009

Some of the Grand Challenges

- Develop food plants to adapt and grow sustainably in changing environments
- Expand sustainable alternatives to fossil fuel
- Develop and manage smart grids
- Provide access to clean water
- Manage the nitrogen cycle
- Restore and improve urban infrastructure
- Develop better forecasting and proactive mitigation strategies for invasive species
- Reverse engineer the brain
- Increase the the spatial resolution of regional climate change models
- Manage and utilize data effectively

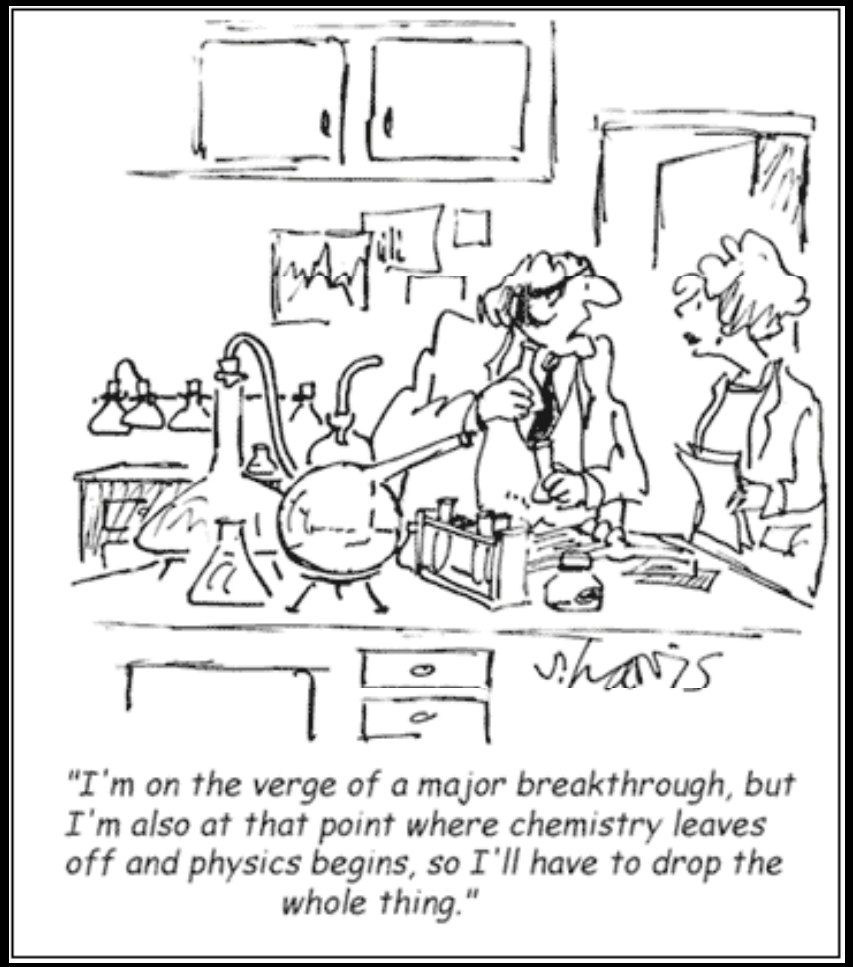
Projected mean surface temperature changes in 2090-2099 for the A1B IPCC scenario




Global mean annual temperature change relative to 1980-1999 (°C)
0
1
2
3
4
5 °C
WATER
Increased water availability in moist tropics and high latitudes
Decreasing water availability and increasing drought in mid-latitudes and semi-arid low latitudes
Hundreds of millions of people exposed to increased water stress
ECOSYSTEMS
Up to 30% of species at increasing risk of extinction
Significant† extinctions around the globe
Increased coral bleaching
Most corals bleached
Widespread coral mortality
Terrestrial biosphere tends toward a net carbon source as:
~15%
~40% of ecosystems affected
Increasing species range shifts and wildfire risk
Ecosystem changes due to weakening of the meridional overturning circulation
FOOD
Complex, localised negative impacts on small holders, subsistence farmers and fishers
Tendencies for cereal productivity to decrease in low latitudes
Productivity of all cereals decreases in low latitudes
Tendencies for some cereal productivity to increase at mid- to high latitudes
Cereal productivity to decrease in some regions
COASTS
Increased damage from floods and storms
About 30% of global coastal wetlands lost‡
Millions more people could experience coastal flooding each year
HEALTH
Increasing burden from malnutrition, diarrhoeal, cardio-respiratory, and infectious diseases
Increased morbidity and mortality from heat waves, floods, and droughts
Changed distribution of some disease vectors
Substantial burden on health services
0
1
2
3
4
5 °C
Global mean annual temperature change relative to 1980-1999 (°C)

IPCC 2007

The Problem with Isolated Disciplinary Thinking



"I'm on the verge of a major breakthrough, but I'm also at that point where chemistry leaves off and physics begins, so I'll have to drop the whole thing."

Addressing Grand Challenges

- Grand Challenges are inherently
  - Interdisciplinary, complex
  - Involves not just science and engineering, but also policy, government, and geopolitics
- Plans to tackle grand challenges should include:
  - Systematic training for future scientists and engineers to take on these challenges
  - Strategic support for interdisciplinary research
  - Cultivate innovation

A consistent theme from the reports is the need for greater emphasis on interdisciplinary training

"The committee recommends that the national New Biology Initiative devote resources to programs that support the creation and implementation of interdisciplinary curricula, graduate training programs, and educator training needed to create and support New Biologists."

National Research Council 2009

What is NSF Doing to Promote Interdisciplinary Research and Training?

NSF and Interdisciplinary Research

- NSF has a long history of encouraging interdisciplinary research (IDR)
- This includes support for proposals that are submitted in response to targeted IDR solicitations and for unsolicited proposals

IDR Solicitations at NSF

- Cross-Directorate and Interagency [examples]

  - Decadal Regional Climate Prediction using Earth Systems Models (EaSM): NSF, DOE, USDA program to fund next-generation Earth System Models
  - Emerging Frontiers in Research and Innovation (EFRI): NSF, DOE, EPA focus this year on Renewable Energy Storage, Science in Energy and Environmental Design
  - Cyber-enabled Discovery and Innovation (CDI): computational thinking in science and engineering research and education
  - Science and Technology Centers (STC): intellectual and physical infrastructures within and between disciplines
  - Dynamics of Coupled Natural and Human Systems (CNH): basic research and related activities to enhance fundamental understanding of the complex interactions within and among natural and human systems\
  - Sustainability initiatives (e.g., Sustainability Research Networks, SRNs)

- Directorate-level Solicitations [examples]

  - Engineering Research Centers (ERC), Materials Research Science and Engineering Centers (MRSEC)

- Division and Program-Level

  - Fostering Interdisciplinary Research on Education (FIRE in DRL): Facilitate the process by which scholars can cross disciplinary boundaries to acquire the skills and knowledge that would improve their abilities to conduct rigorous research on STEM learning and education.

118 of 342 (35%) active NSF solicitations in 2008 included the term "interdisciplinary"

What About Interdisciplinary Graduate Student Training?

The NSF Integrative Graduate Education and Research Traineeship (IGERT) program was started in 1998 to address national calls for greater emphasis on interdisciplinary training in graduate education.

NSF awards IGERT awards to institutions that develop innovative, interdisciplinary doctoral training and research programs in science, technology, engineering, and mathematics (STEM) disciplines

Purpose of IGERT

"catalyze a cultural change in graduate education, for students, faculty, and institutions, by establishing innovative models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries"

NSF 2010

IGERT Goals

- Interdisciplinary training and research experience
- Deep knowledge in chosen disciplines
- Innovative educational plan
- Technical, professional, and personal skills
- Develop career skills desired by both academic and non-academic employers
- Intended to catalyze sustainable institutional change in graduate education for the training of future scientific research workforce
- Broadening participation

Some Features of IGERT

- Encourages experiments that may result in changes of existing models for Graduate Education
- Emphasizes both integrated training and research
- Provides a framework wherein institutions, through PIs, can propose programs with enough flexibility to accommodate students' desire to design an education plan to match his/her career goals
- Provides a detailed means for program performance assessment
- Creates a culture for graduate students that transcends departmental and disciplinary boundaries.

Some Realities of Educational Institutions

"colleges an universities have evolved an organizational structure that is tightly coupled to traditional disciplines (Clark 1984) and thus ill equipped to foster interdisciplinary research, teaching, and learning"
Borrego et al. 2012

"The organizational culture of the university is one divided by disciplinary ways of thinking and behaving" (Holley 2009)
Cited by Borrego et al. 2012

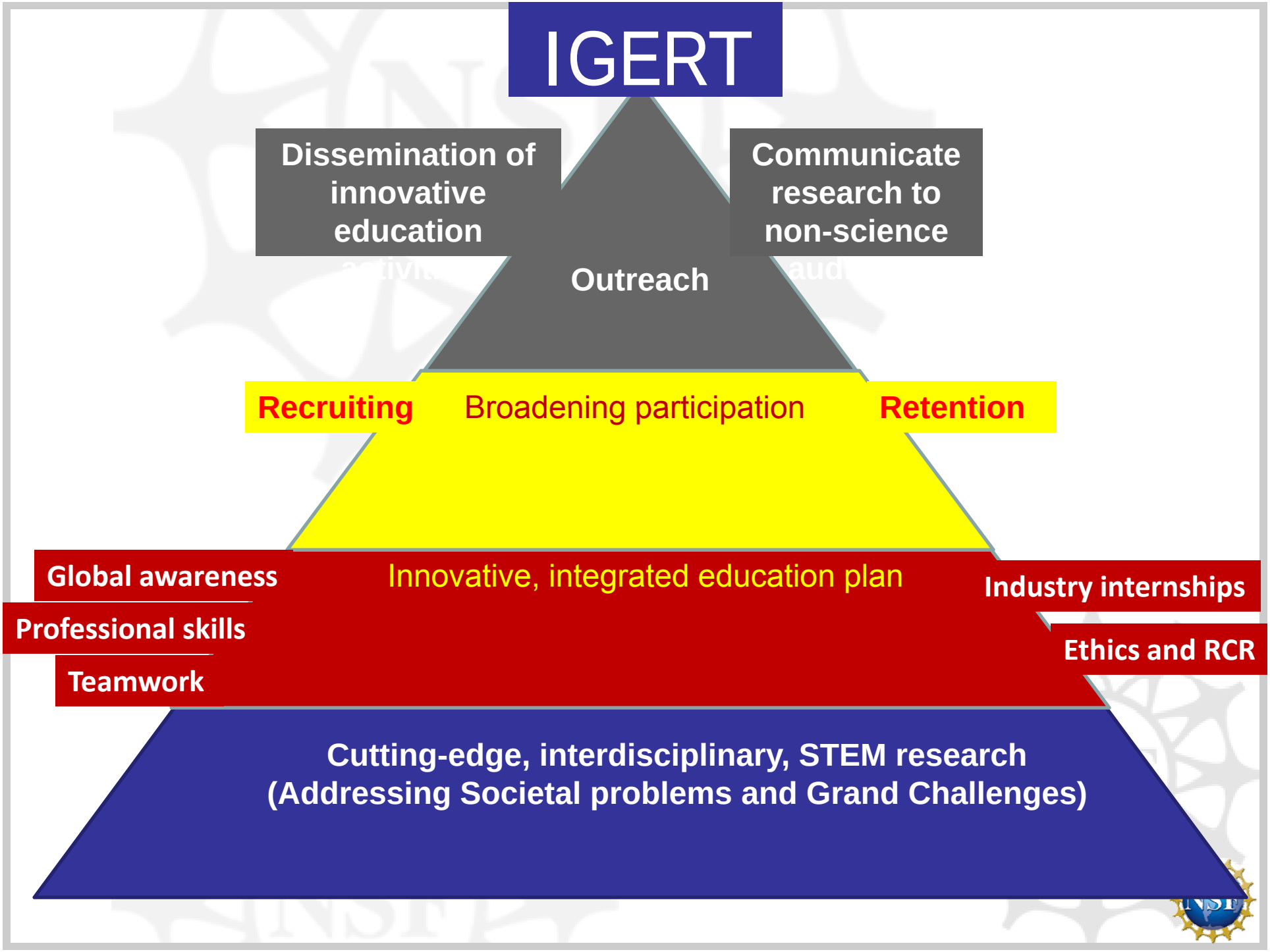
Integrative Graduate Education and Research Traineeship (IGERT)

- Since 1997
  - 278 awards
  - 122 different lead institutions
  - 43 states, DC, and Puerto Rico
  - >5,200 PhD students have been supported
  - Some institutions have had multiple awards (9 is the highest so far)
- Most recent competition had 154 proposals, ~18 awards (11.6%)

Support Level-Details

- 5-year awards (up to $3.6M)
- Up to $600K per year
- Up to $200K additional in the first year for equipment, special materials, or methodologies, part of the total $600K
- Supplemental International Training Component $50K per year for years 2-5
- Competitive Incentive Fund $200K (innovative activities)
- Graduate student stipend $30,000, Cost of education expenses $10,500
- Full ICR rate

Keys to a Successful Application


IGERT
Dissemination of innovative education
Communicate research to non-science
Outreach
Recruiting
Broadening participation
Retention
Global awareness
Innovative, integrated education plan
Industry internships
Professional skills
Ethics and RCR
Teamwork
Cutting-edge, interdisciplinary, STEM research
(Addressing Societal problems and Grand Challenges)

Some Selected IGERT Interdisciplinary Themes

- Smart sensors and integrated devices
- Sequential decision-making
- Urban ecology and infrastructure
- Resilience and adaptation to climate change
- Nanotoxicology

Some examples of IGERT Projects

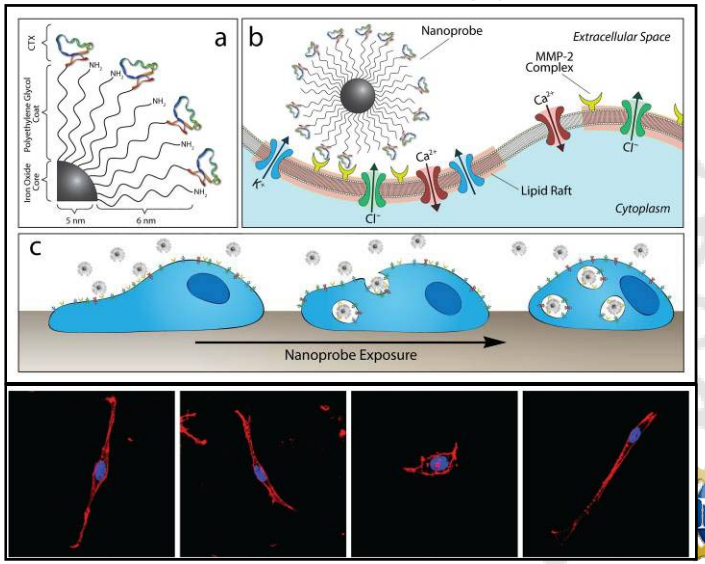
IGERT Examples

IGERT: Marine Sustainability
University of Alaska
PI: Ginny Eckert

Goal: Double the # of Alaskan Native PhD Graduates from UAF

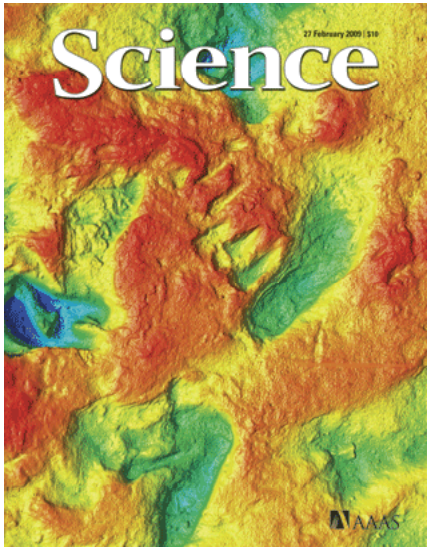
IGERT: Nanotechnology
University of Washington
PI: Marjorie Olmstead

Education achievement: America's first PhD program in Nanotechnology



Theme: Environmental Change and Implications for Humanity

Dartmouth: Polar Environmental Change



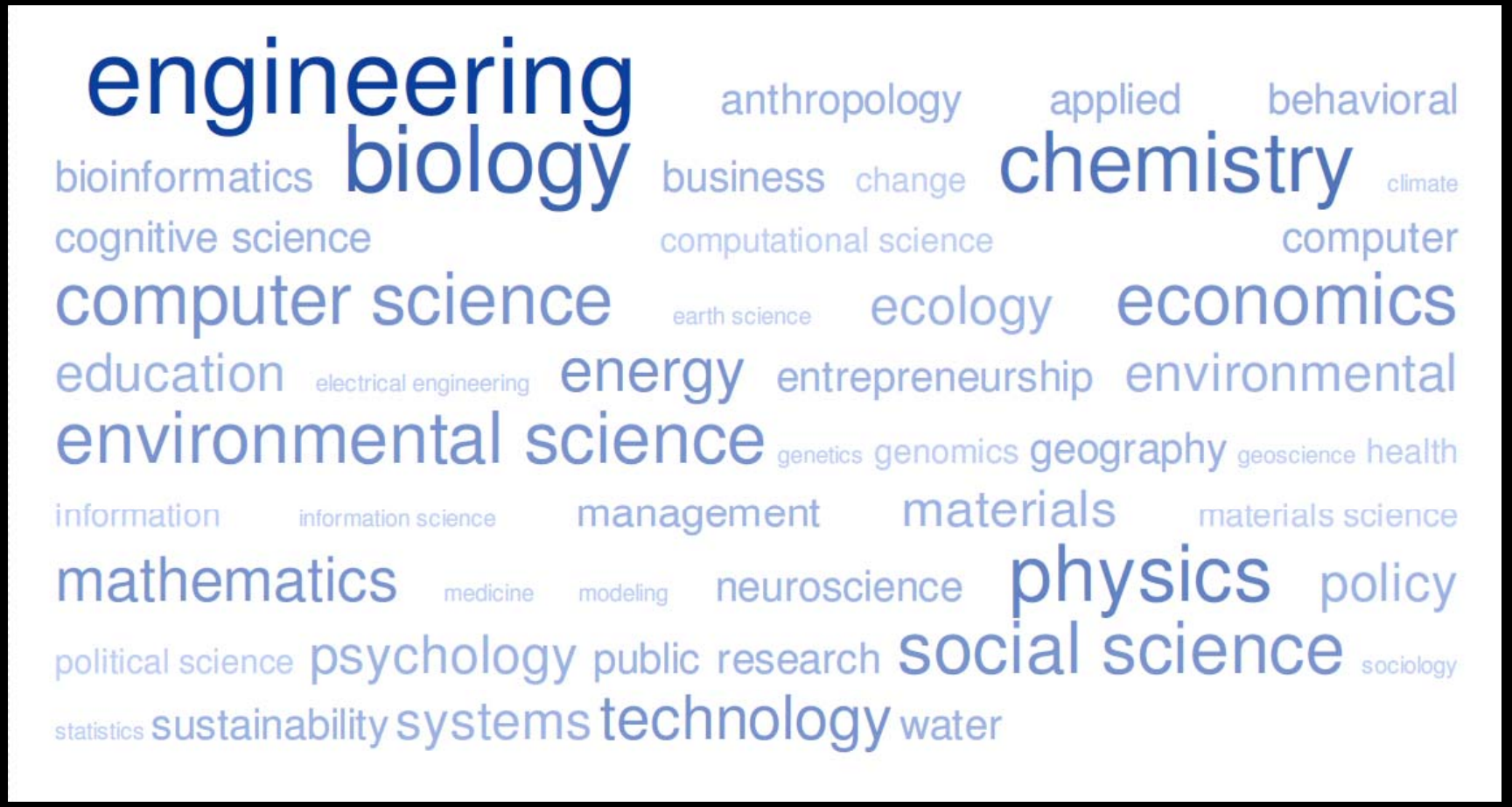
George Washington University: Dynamics of Behavioral Shifts in Human Evolution: Brains, Bodies, and Ecology

UCSD: Marine Biodiversity: Understanding Threats and Providing Solutions

But the best way to get an overview of the themes of funded projects is to go to www.igert.org

www.igert.org

Themes of Most Recent IGERT Submissions



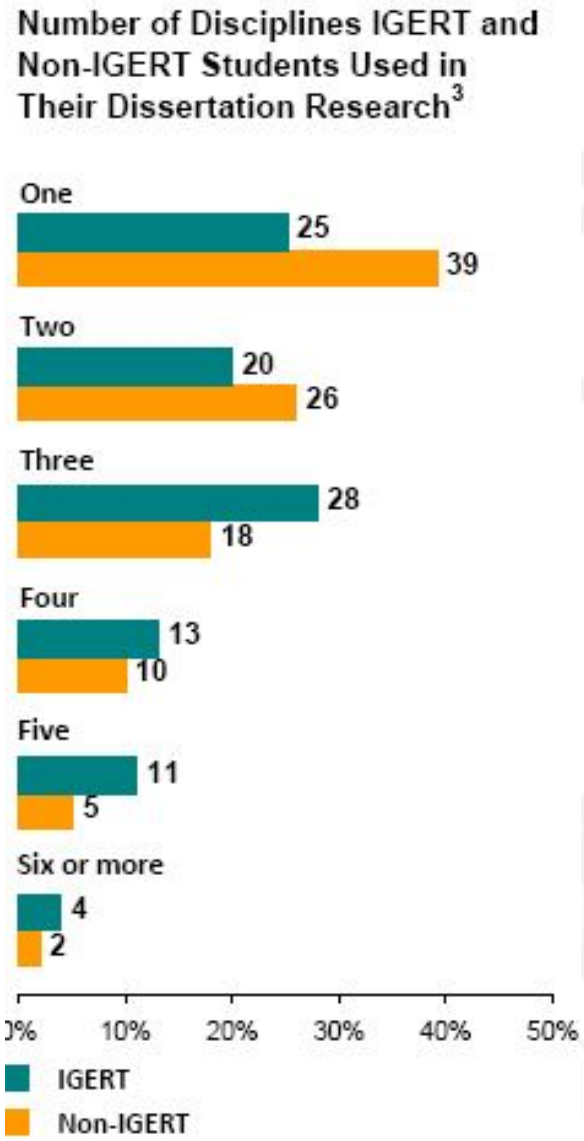
What about IGERT Graduates?

- Where do they go?
- What do they do?
- What experiences do they take with them?
- What do they say about their experience with IGERT?

Comparison study Spring 2008

- IGERT graduates (869) compared with doctoral recipients from similar academic departments that did not have an IGERT (827)
  - *IGERT is in high demand. High proportions of both IGERT and non-IGERT graduate reported that they were interested in interdisciplinary education when applying to graduate schools (85 and 75%, respectively)*
  - *IGERT graduates value their training. The interdisciplinary nature of IGERT training was consistently referred as the most valuable aspect.*

Comparison study Spring 2008



IGERT Graduates complete multi-disciplinary dissertations

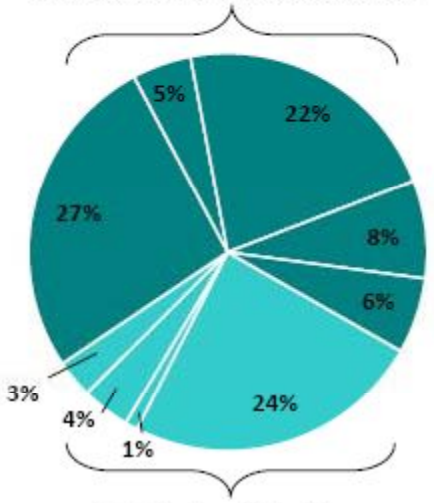
- *75% of IGERT graduates report involving at least two disciplines in their dissertation research compared to 61% in the non-IGERT group.*
- *56% of IGERT graduates report involving ≥3 disciplines in their dissertation research.*

Comparison study Spring 2008

- IGERT graduates as likely to complete degrees as comparison students – yet in less time
  - *IGERT students are required to participate in multiple activities, ranging from additional courses, to seminars, discussion groups, laboratory rotations, research projects, and internships; many activities beyond students' home department requirements.*
  - *Despite such additional requirements, IGERT graduates successfully earn PhD degrees at rates comparable to those reported in the Council of Graduate School's PhD Completions Project.*
  - *IGERT graduates completed on average six months sooner than comparison group*.

Comparison study Spring 2008

IGERT Graduates in the Workforce, One to Eight Years After Graduation[6]



- IGERT graduates obtain the professional positions they pursue
  - *Surveyed PhD graduates between one and eight years of Post-PhD employment either in the workforce (68%) or Postdoctoral appointment (32%)*
  - *27% were in Academic Faculty positions*
  - *23% were in Industry*
  - *44% were outside academia*

Comparison study Spring 2008

- IGERT Training a positive factor in job attainment
  - *94% of IGERT graduates believe that the IGERT experience helped them find professional positions.*
  - *They felt IGERT training was a competitive advantage*
  - *Less difficulty in landing on their first job*

Comparison study Spring 2008

- IGERT provides graduates with needed skills and intellectual breadth
  - *IGERT graduates report drawing upon interdisciplinary networking and collaboration skills in their current professional roles*
  - *IGERT graduates report regularly drawing from two or more disciplines in their current work*
  - *IGERT graduates report working on scientific /technical projects and/or teaching courses that require the integration of multiple disciplines more than their non-IGERT peers.*

IGERT Graduate Feedback

- *"I got this job because I could explain why quantum theoretical/computational chemistry is important to a group of experimentalists. Without IGERT, I would not have been able to do this as well as I did."*
- *"I was hired because I am a computer programmer that is fluent in biology. People like this, who really can cross the disciplines and…appreciate the subtle, yet very significant, differences in how different groups think about problems and data, are very rare."*

IGERT Graduate Feedback

- ***"Without IGERT's interdisciplinary training, I would not be able to conduct the research I do. My training allows me to integrate formal, mathematical, and computer science methods with the experimental techniques of applied psychology. If I had attended a traditional graduate program I would have a subset of these skills, and I would not know how to truly integrate them."***

Challenges for IGERT Trainees

- Coping with an interdisciplinary curriculum with disciplinary depth
- Having a critical mass and support group
- Role models
- Counseling to secure faculty positions

Challenges for IGERT Faculty

- Departmental requirements
- Cultural differences among departments
- Administrative load on PI, faculty
- Release time or credit for faculty teaching
- Recognition for interdisciplinary teaching at (tenure or) promotion

Challenges for IGERT Institutions

- Rewarding interdisciplinary graduate education by faculty
- Hiring new faculty outside traditional disciplines
- Rewarding interdisciplinary research by young faculty
- Overcoming resistance or inertia
- Sustainability

NSF Resources for the Innovation Ecosystem

- Grow the existing portfolio and strengthen the translational phase
- Extend the reach of industry-driven research initiatives
- **Educate to innovate**
- Better understand the social dimensions of innovation (SciSIP)

Undergraduate Programs

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NSF Undergraduate Programs

- Transforming Undergraduate Education in STEM (TUES)
- Robert Noyce Teacher Scholarship Program (Noyce)
- S-STEM Scholarship Program (S-STEM)
- STEM Talent Expansion Program (STEP)
- Math-Science Partnership Program (MSP)
- Federal Cyber Service: Scholarships For Service (SFS)