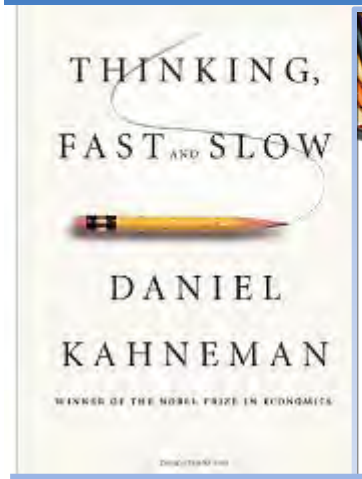
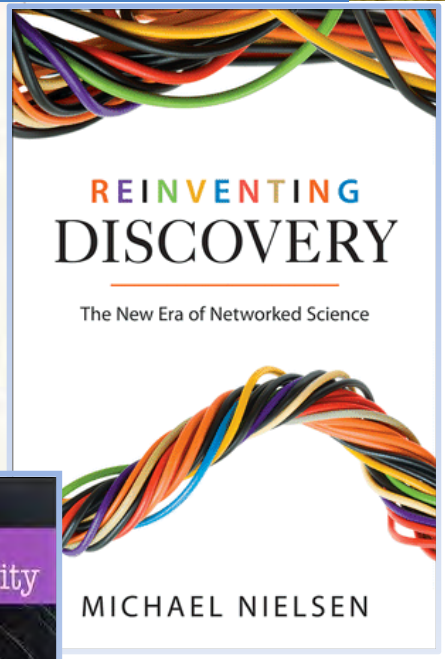
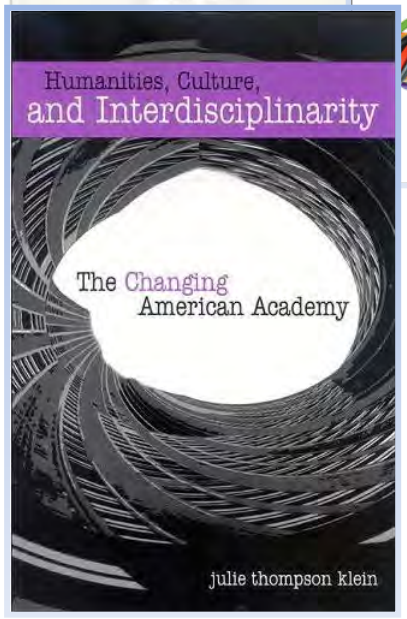
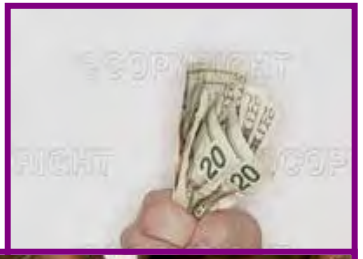
Jonathan Borwein
Laureate Professor
and Director CARMA
www.carma.newcastle.edu.au







Interdisciplinarity, Innovation, Collaboration and Creativity: How to Manage a Research Portfolio



CARMA

dis·ci·pline –*n.* (Webster) 9. a branch of instruction or learning: *the disciplines of history and economics*.

"I never run for trains." Nasim Nicholas Taleb (The Black Swan)

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Revised 12-09-2012

Interdisciplinarity, Innovation, Collaboration and Creativity or How to Manage a Research Portfolio

ABSTRACT I will discuss four much abused words

Interdisciplinarity, Innovation, Collaboration and Creativity.

I will describe what they mean for different stakeholder groups and will speak about my own experiences as a research scientist, as a scientific administrator, as an educator and even as a small high-tech businessman.

I will also offer advice that can of course be ignored.

3. Publish the same result several times. *4. You are more likely to be remembered by your expository work.* – Gian-Carlo Rota [1932-1999], "Ten lessons I wish I had been taught" (1996)

See also Teaching and Learning with Technology (2011 ALTC lecture)

Innovation and Creativity (I&C): Some Definitions

(guiding not prescriptive)

in·no·va·tion, *noun.* (Webster)

1. the introduction of something new
2. a new idea, method, or device : NOVELTY [Date: 15th century]

Our masters often use a different "hard" definition which requires "bringing products and services to market." (portfolio management)

cre·a·tiv·i·ty, *noun.* (Webster)

1. the quality of being creative 2 : the ability to create

[Date: 1875] Main Entry: cre·a·tive *adjective* [Date: 1678]

1. marked by the ability or power to create : given to creating *the creative impulse*
2. having the quality of something created rather than rather than imitated: IMAGINATIVE *the creative arts*
3. managed so as to get around legal or conventional limits *creative financing*

also: deceptively arranged so as to conceal or defraud *creative accounting*

CREATIVITY a la MIHALY CSIKSZENTMIHALYI (1997)

"My work in this area has convinced me that creativity cannot be understood by looking only at the people who appear to make it happen. Just as the sound of a tree crashing in the forest is unheard if nobody is there to hear it, so creative ideas vanish unless there is a receptive audience to record and implement them. And without the assessment of competent outsiders, there is no reliable way to decide whether the claims of a self-styled creative person are valid.

"According to this view, creativity results from the interaction of a system composed of three elements: a culture that contains symbolic rules, a person who brings novelty into the symbolic domain, and a field of experts who recognize and validate the innovation. All three are necessary for a creative idea, product, or discovery to take place."

- Talks need audiences, seminars need participants

Innovation a la Wikipedia

"An **innovation** is a new way of doing something. It may refer to incremental and emergent or radical and revolutionary changes in thinking, products, processes, or organizations. Following *Schumpeter* (1934), contributors to the scholarly literature on innovation typically distinguish between **invention**, **an idea made manifest**, and **innovation**, **ideas applied successfully in practice**.

- In many fields, something new must be substantially different to be innovative, not an insignificant change, e.g., in the arts, economics, business and government policy. In economics the change must increase value, customer value, or producer value. The goal of innovation is positive change, to make someone or something better. Innovation leading to increased productivity is the fundamental source of increasing wealth in an economy."

Interdisciplinarity and Collaboration (I&C): Some Definitions

in·ter·dis·ci·pli·nar·y, *adj.* (Webster)

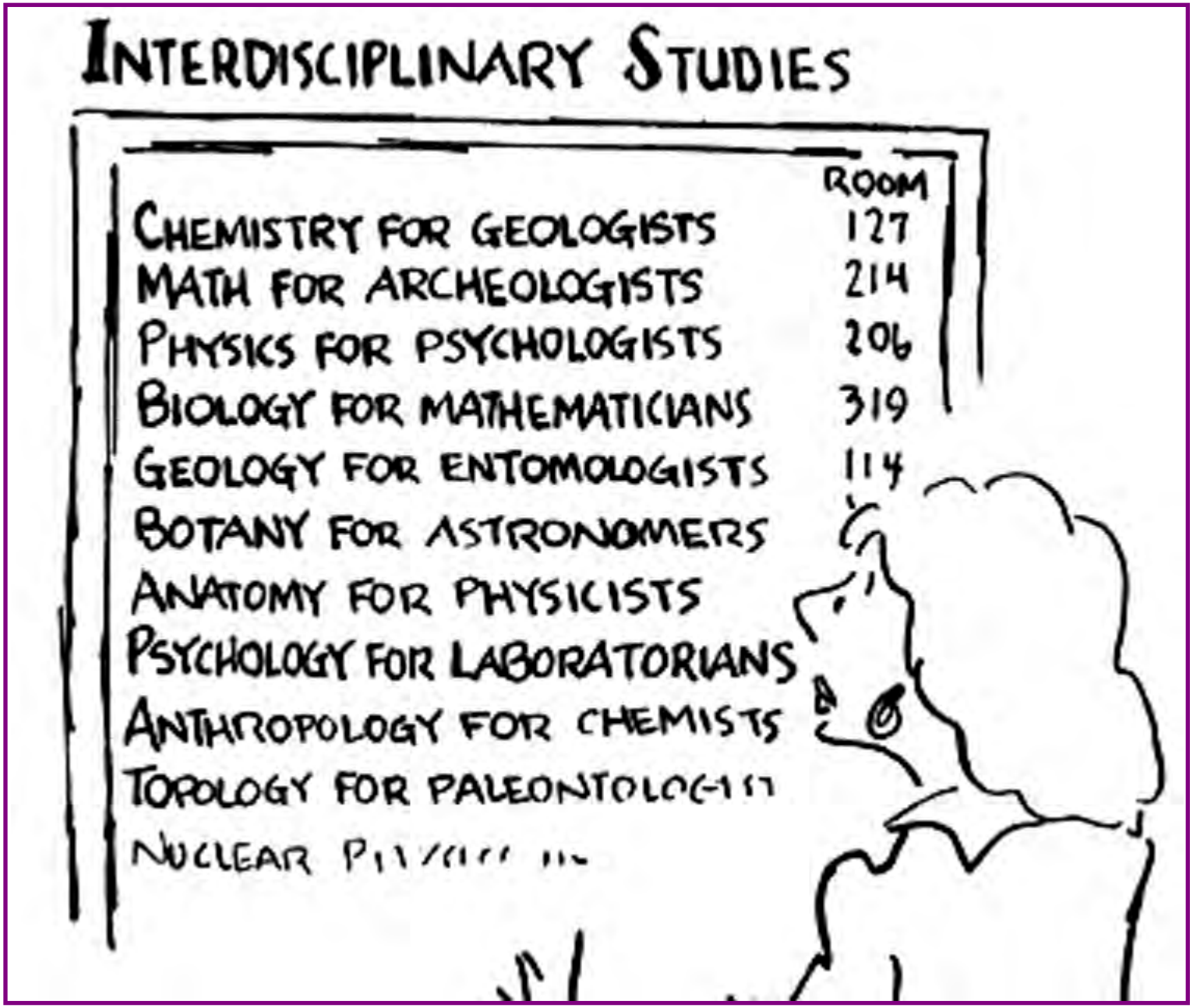
1. combining or involving two or more academic disciplines or fields of study: *The economics and history departments are offering an interdisciplinary seminar on Asia.*
2. combining or involving two or more professions, technologies, departments, or the like, as in business or industry.

[1935–40; INTER- + DISCIPLINARY]

Often tightly coupled with collaboration but not of necessity.
How many disciplines sit in *your* Faculty? How many spill over?

col·lab·o·rate, *v.i.* (Webster)

1. to work, one with another; cooperate, as on a literary work: *They collaborated on a novel.* [1870–75]
2. Nasty meaning: to cooperate, usually willingly, with an enemy nation, *He collaborated with the Nazis during World War II.*


INTERDISCIPLINARY STUDIES
ROOM
CHEMISTRY FOR GEOLOGISTS 127
MATH FOR ARCHEOLOGISTS 214
PHYSICS FOR PSYCHOLOGISTS 206
BIOLOGY FOR MATHEMATICIANS 319
GEOLOGY FOR ENTOMOLOGISTS 114
BOTANY FOR ASTRONOMERS
ANATOMY FOR PHYSICISTS
PSYCHOLOGY FOR LABORATORIANS
ANTHROPOLOGY FOR CHEMISTS
TOPOLOGY FOR PALEONTOLOGISTS
NUCLEAR PHYSICS

IIC&C: what works, what doesn't

Some General Observations

- Modern Research is Global and increasingly demands Interdisciplinary Collaboration
  - building knowledge & social networks is crucial
  - virtual and actual networks are complementary
- Proposals, Papers, Presentations must simultaneously reach diverse groups
  - experts are rare; knowledge is not; information is over abundant
- Success rates are low (20%?)
  - so ideas must be repurposable
- Interdisciplinary collaboration can be great fun or very painful:
  - every University has both many collegial assets and serious institutional impediments

Drive

I&C: what works, what doesn't

Further General Observations

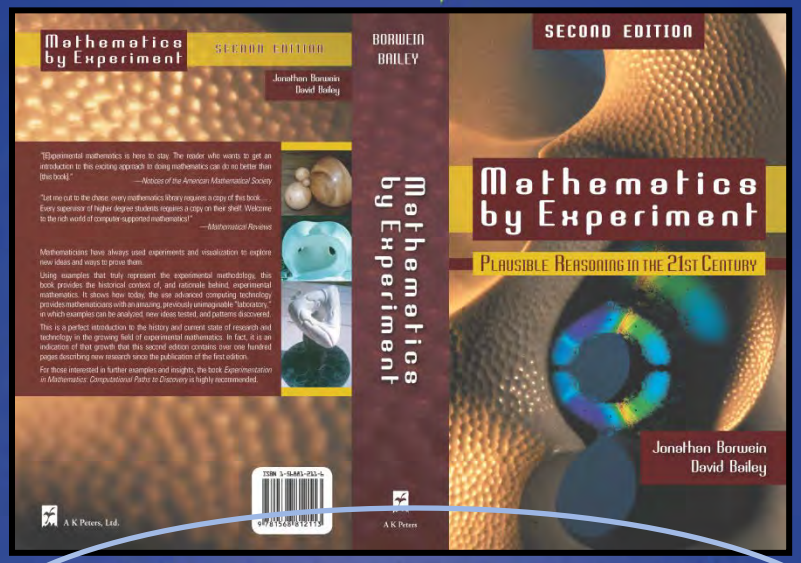
- distinct mediocre competences do not often make a good interdisciplinary marriage; but
  - Faraday *``A centre of excellence is, by definition, a place where second class people may perform first class work.''*
  - Robin Wilson *``At Oxford they thought me a second-rate research mathematician and a first-rate teacher. At the OU just the opposite…''*

- You/we are your/our own best proponents (sales-people)
  - but bullshit is really obvious

- E.g., I advocate Experimental (Inductive) Mathematics
  $\neq$ sloppy experiment + missing proofs
  (though many try to publish such)

Experimental Mathematics in Action

David H. Bailey
Jonathan M. Borwein
Neil J. Calkin
Roland Girgensohn
D. Russell Luke
Victor H. Moll



"Computing is to mathematics as telescope is to astronomy: it might not explain things, but it certainly shows 'what's out there.' The authors are expert in the discovery of new mathematical 'planets,' and this book is a beautifully written exposé of their values, their methods, their subject, and their enthusiasm about it. A must read."

—**Prof. Herbert S. Wilf**, author of *generatingfunctionology*

"From within the ideological blizzard of the young field of Experimental Mathematics comes this tremendous, clarifying book. The authors—all experts—convey this complex new subject in the best way possible; namely, by fine example. Let me put it this way: Discovering this book is akin to finding an emerald in a snowdrift."

—**Richard E. Crandall**, Apple Distinguished Scientist, Apple, Inc.

ISBN 978-1-56881-271-7

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LUKE
MOLL

Experimental Mathematics in Action

AK PETERS

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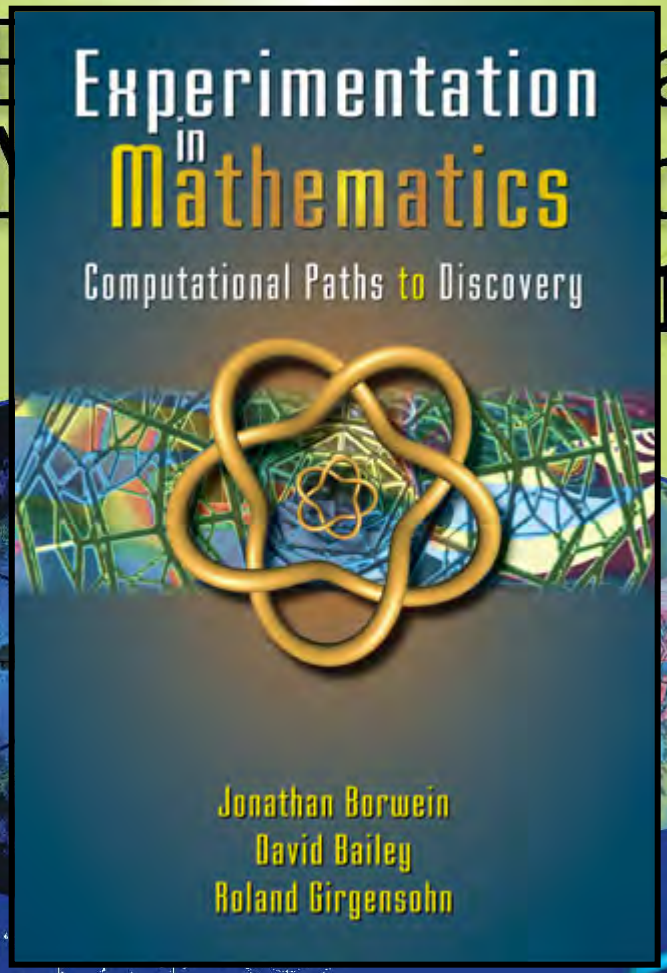
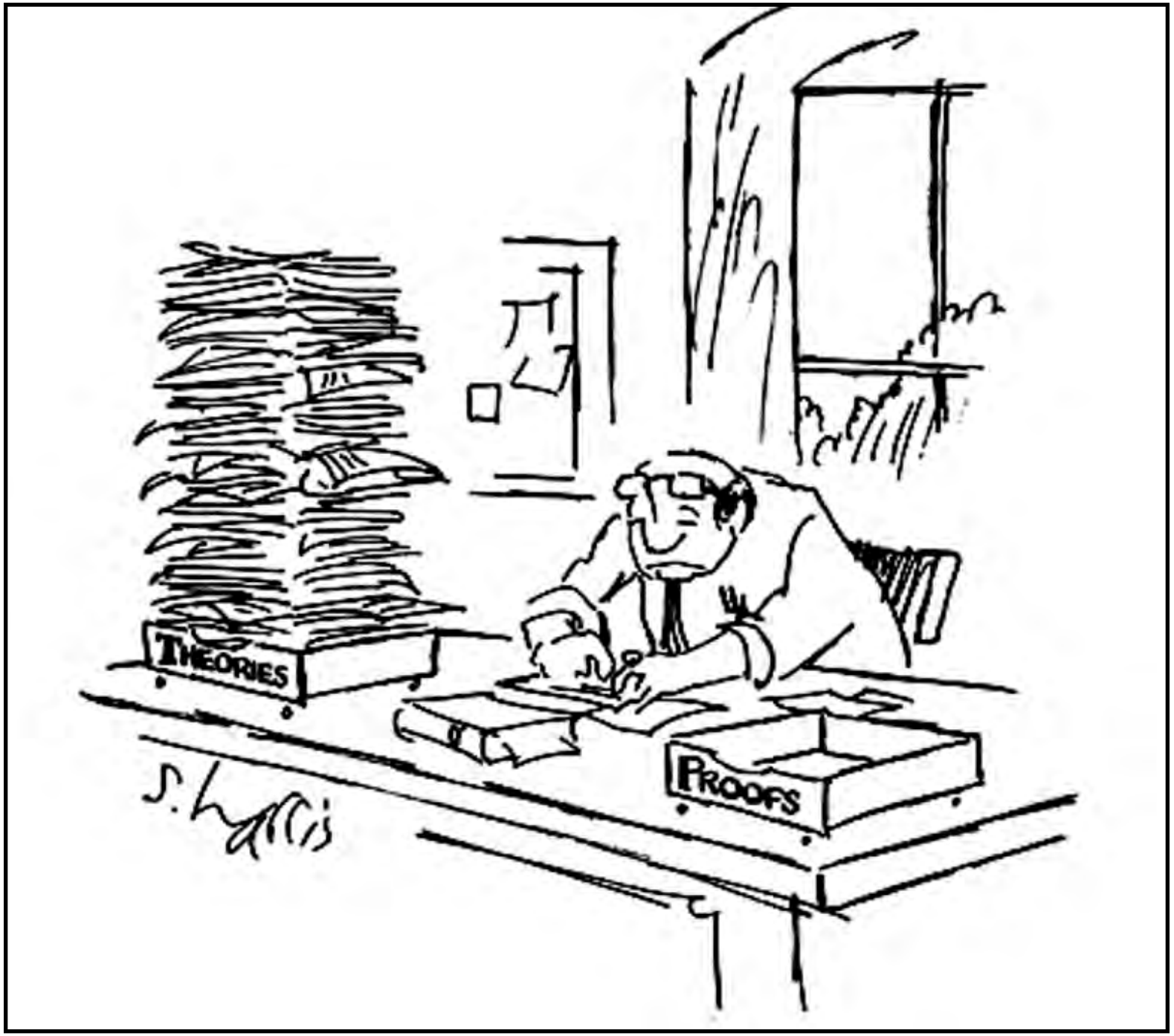
More use of visualization please



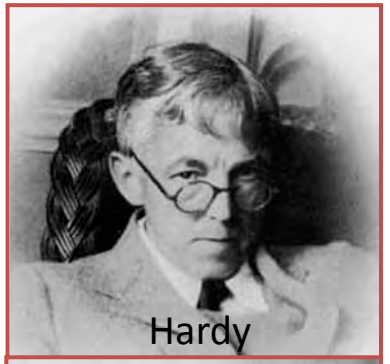

THEORIES
PROOFS

Hardy & Littlewood's Four Axioms for Collaboration

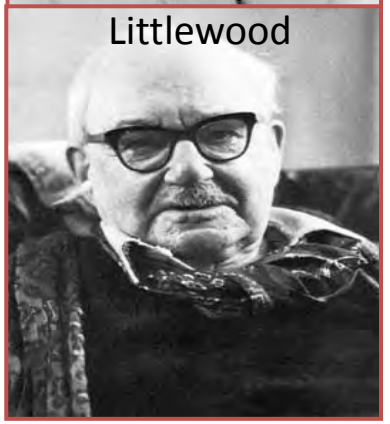
(Harald Bohr, 1887-1951)

``The first [axiom] said that when one wrote to the other (they often preferred to exchange thoughts in writing instead of orally), it was completely indifferent whether what they said was right or wrong. As Hardy put it, otherwise they could not write completely as they pleased, but would have to feel a certain responsibility thereby.

The second axiom was to the effect that, when one received a letter from the other, he was under no obligation whatsoever to read it, let alone answer it, --- because, as they said, it might be that the recipient of the letter would prefer not to work at that particular time, or perhaps that he was just then interested in other problems....



Hardy



Littlewood

G.H. Hardy (1877-1947) & J.E. Littlewood (1885-1977)
Four Axioms for Collaboration

The third axiom was to the effect that, although it did not really matter if they both thought about the same detail, still, it was preferable that they should not do so.

And, finally, the fourth, and perhaps most important axiom, stated that it was quite indifferent if one of them had not contributed the least bit to the contents of a paper under their common name; otherwise there would constantly arise quarrels and difficulties in that now one, and now the other, would oppose being named co-author."

- Pretty good rules for collaboration a century later
- Shared (even expressed) expectations are crucial!
- IP issues & treatment of students often need addressing (dot-com)

The most celebrated collaboration in mathematics; the post office worked then!

Modern academic life on one slide

"THE ROYAL ACADEMY OF SCIENCE IS WILLING TO PAY YOU FOR THIS APPLE TREE, IF YOU'LL SHARE WITH US ANY IDEAS YOU GET FROM IT."

NYT circa 1995

"On the Internet, nobody knows you're a dog."

IIC&C: My own Evolution

- Pure Math (71) → Optimization (Multicriteria Choice, DPhil 74) → OR + Computational Science (84)→ High Performance Comp, Imaging (94) → Collaborative Technology (04) → CARMA (08)
  - Spun off **MathResources** Inc (90-94) IRAP/Angel funding (97-03) $3M Reg. Dev.
  - Many employees, products, prizes, partners (SGI, Casio, Maple, NSF, MAA), no IPO.
- I wouldn't have felt comfortable writing my recent books without having studied some Logic, Philosophy & History (of Science)
- One of my most challenging experiences was building WestGrid and coauthoring and advocating the 2005 Long Range Plan for Advanced Computation in Canada (2003-2005) for all disciplines
  - E.g., to Science Advisor, Grant Councils, Space Agency, Politicos
  - Led to recent $350 million infusion for Compute Canada

Historic CERN Discovery Made Possible in Part by Compute Canada Resources (Higgs)

Three Rings: National HPC Needs

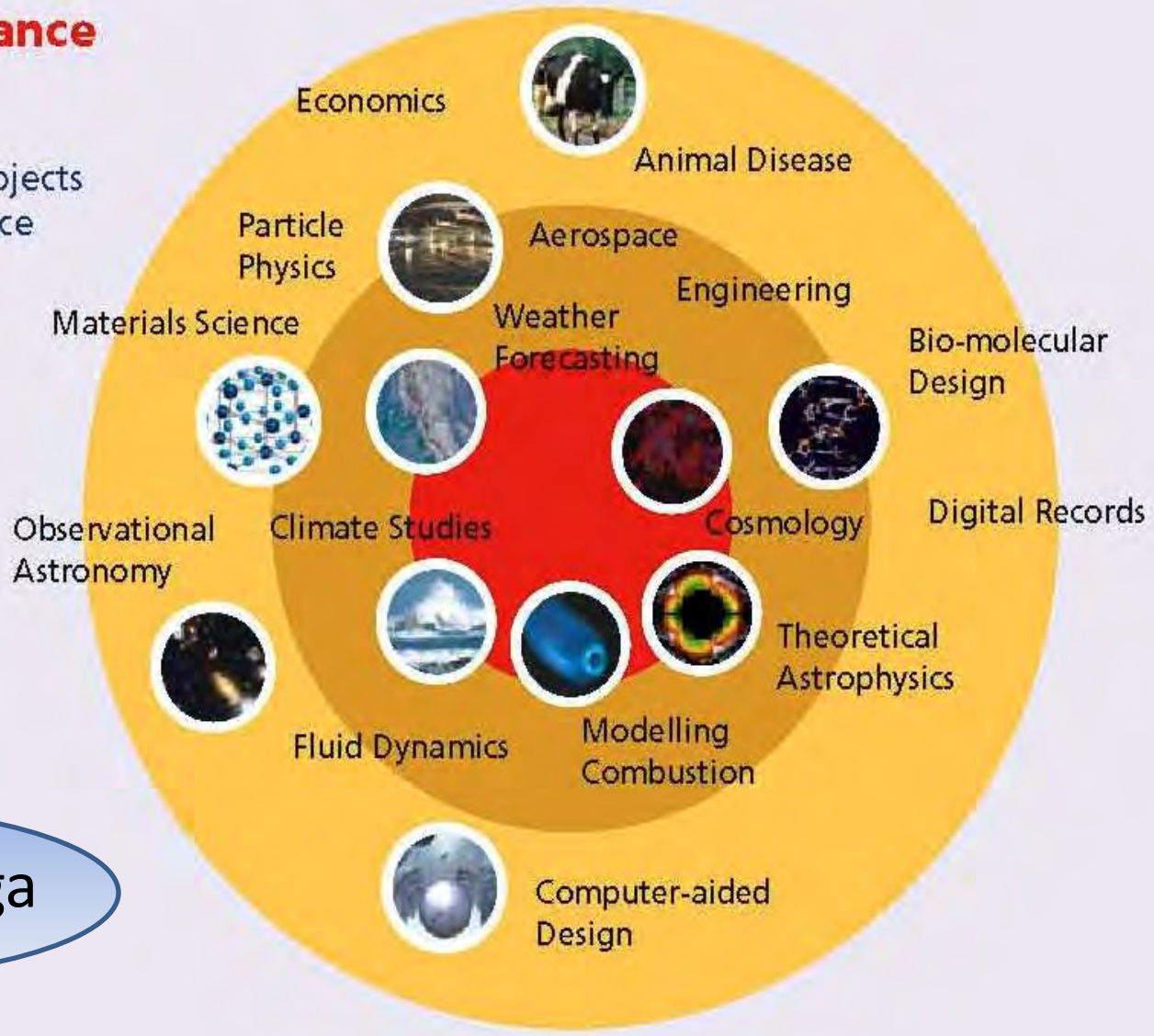
High Performance Computing Needs

The array of canadian research projects each have unique high performance computing requirements.

Ring 1
Desktop Computers
(1-64 processors)

Ring 2
Small Cluster System
(64-300 processors)

Ring 3
Supercomputers /
Terascale System

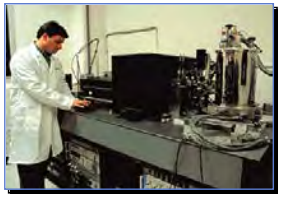


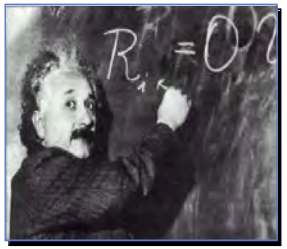
Tera-Peta-Bigga

Changing Research Landscape: a new Triad

Computational

(dry science)





Experimental

(wet science)

Theoretical

(hard science)

"When the facts change, I change my mind. What do you do, sir?"

(John Maynard Keynes)

Granting Council and Faculty **boundaries** are a huge impediment

My Labs in Canada and Oz:
time is the new distance

VANCOUVER:4H

TOKYO:11H

LOS ANGELES:4H

WASHINGTON:1H

TEL AVIV:6H

NEW DELHI:9.5H

5-7 hours

Within 5 hours difference

BRASILIA:1H

SANTIAGO:0H

CAPE TOWN:6H

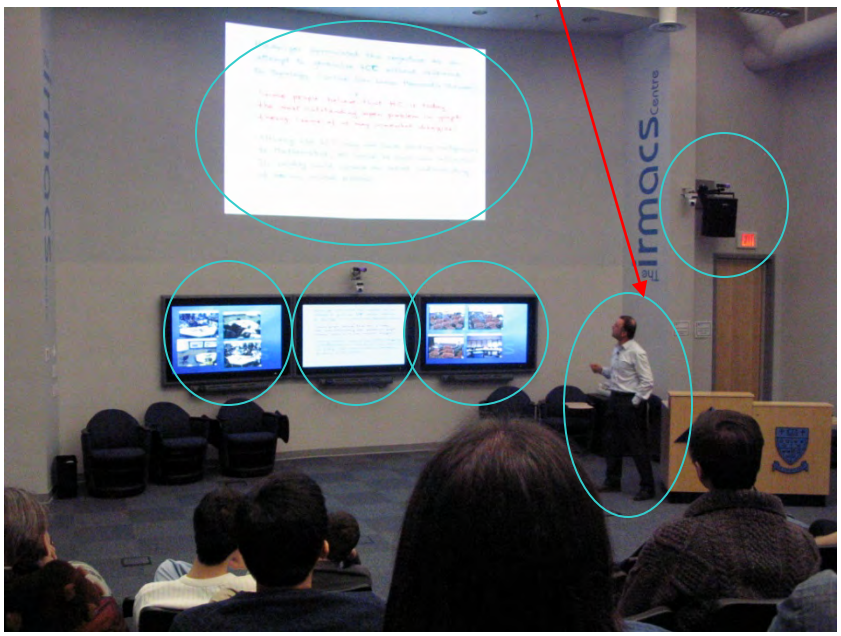
240 cpu Glooscap at Dal

Dalhousie Distributed
Research Institute and
Virtual Environment

D-Drive's Nova Scotia location lends us unusual freedom when interacting globally. Many cities around the world are close enough in a chronological sense to comfortably accommodate real-time collaboration.

Since 2005: C2C Biweekly National Colloquium:
Samples: from Simon Fraser and Edmonton

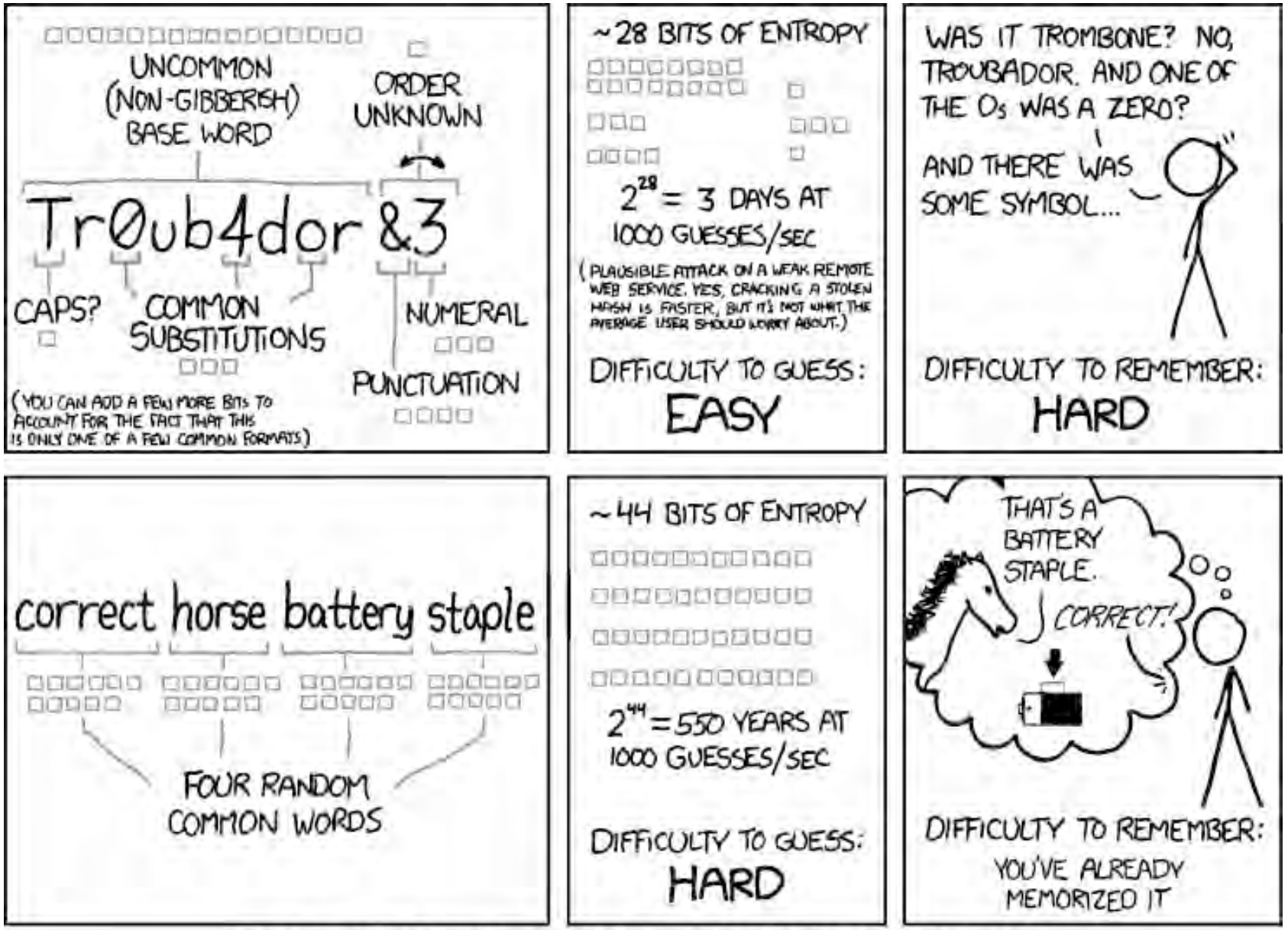
Solver of Checkers
Top 10 *Science* pick for 2008



Local Presentation
Speaker
Presentation Slides

Remote Presentation
Remote Audience
Local Camera Placement

Sci Com 2012. Production not demo -- everything is rehearsed and carefully planned



THROUGH 20 YEARS OF EFFORT, WE'VE SUCCESSFULLY TRAINED EVERYONE TO USE PASSWORDS THAT ARE HARD FOR HUMANS TO REMEMBER, BUT EASY FOR COMPUTERS TO GUESS.

IIC&C: Success Relies On

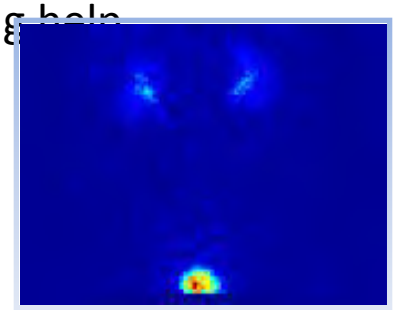
- Willingness to take reasonable risks
  - but should be viewed like portfolio diversification
    - the Andrew Wiles model is not recommended

- Lack of fear & mutual respect for the other's discipline:

  "Hardy asked `What's your father doing these days. How about that esthetic measure of his?' I replied that my father's book was out. He said, 'Good, now he can get back to real mathematics'." (Garrett Birkhoff on his father's book Aesthetic Measures, 1933).
  - many physicists fear mathematicians; who are often uncomfortable or dismissive of informal reasoning and 'physical or economic intuition'

- Sufficient common language
  - a slow process as I found in a decade working with Vancouver Hospital's Medical Imaging Group (especially clinicians and Siemens). Several PhDs, 2 patents …
    - web and 'cloud-computing` tools ; modeling and computing help

- Above all, a real project which interests all
  - not grant *foraging* or publication snaring
  - much facilitated by *good* shared senior HRD students/PDFS
  - weak under-prepared students drown

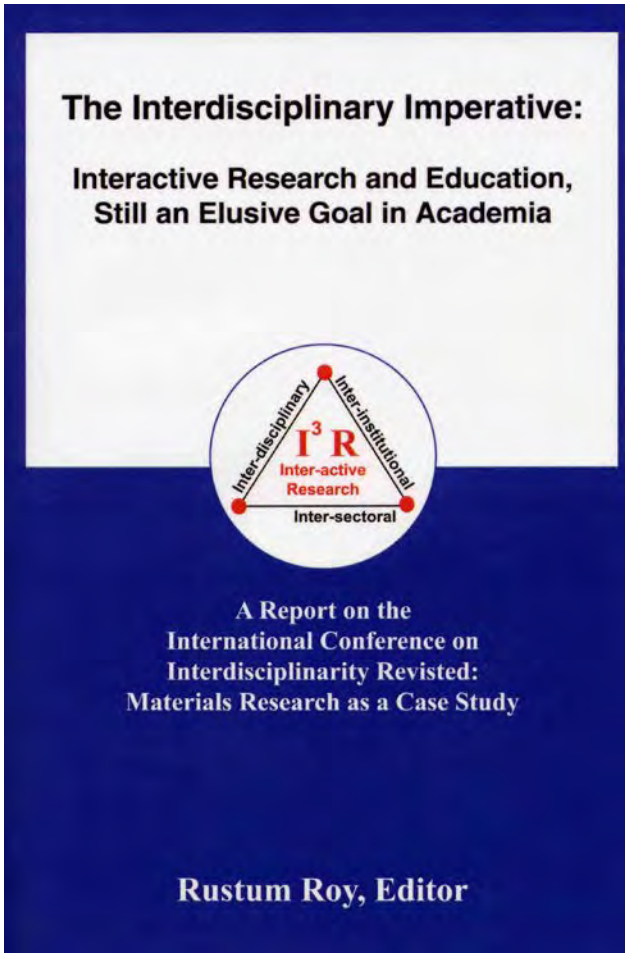


My French collaborator's renal system

Interdisciplinarity: Success Relies On?

- The view of one of the enthusiasts Roy (2000):
  - "there is no successful single institution example of 'I3R'"
    - most Uni's are clueless about technology transfer and IP
    - we are not Harvard or even Melbourne
  - are things changing now?
  - MITACS as a model?

The key findings include the following: The entire research enterprise demands and is moving toward "interactive research" (**Interactive includes inter-disciplinary, inter-institutional, and inter-sectoral research**); The university world has, by and large, failed to organize itself to respond to this new reality; Specific hindrances to I3R are the traditional peer review process and academic intellectual property practices; New directions proposed include: *funding largely on past performance* and matching fund strategies.



"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."

IIC&C: what works, what doesn't

"Keynes distrusted intellectual rigour of the Ricardian type as likely to get in the way of original thinking and saw that it was not uncommon to hit on a valid conclusion before finding a logical path to it.

'I don't really start', he said, 'until I get my proofs back from the printer. Then I can begin serious writing.' " (Alec Cairncross, 1996, in Keynes the Man)

- 50 years after Keynes' death
- GHH & JMK only scientists in Apostles
- I am an *unreconstructed* Keynesian

``*Far better an approximate answer to the right question, which is often vague, than the exact answer to the wrong question, which can always be made precise.''* (J. W. Tuckey, 1962)

Ability to exchange intuition is fundamental to interdisciplinary-collaborative success

IIC&C: Some of my Major Assessment Experience

- **NSERC** Collaborative Research Initiatives (1992-96)
  - *Big Science* from SNO to NASA and Global Warming
  - the more interdisciplinary the panel, the more protective members become of their own disciplines
    - the gaps in one's own field are glaring -- in others not so
      - ✓ *"algorithms will be developed"*
    - very few good *metrics* of success are known
- **NATO** Collab. Res. Grants, Phys. Sci., Eng. and Tech. (1997-2000)
  - 2000 a Georgian sat on the committee; Kosovo and Albright intervened
- **NRC-CISTI Board** (1997-2003 Chair 01-03)
  - Can. Inst. for Sci.&Tech. Info: National Science Library &Press, **IRAP** (small industry) etc.
- **Killam Committee** of Canada Council for the Arts (2003-06)
  - great good will---but "Two solitudes" (Hugh MacLennan) and "Two Cultures" (CP Snow) both reared their heads
    - The Killam trust is the size of the Nobel
- **Excellence in Research for Australia 2010 and 12** (MIC Committee)
  - I am "non-disclosed" but happy to answer some questions

"YOU CAN'T IMAGINE HOW TIGHT OUR BUDGET IS. WE CAN ONLY WORK WITH SINGLE-DIGIT NUMBERS."

Creativity: Some Consequences

- Many breakthroughs are made on boundaries of disciplines, often by brilliant interlopers
  - You have to speak enough of the new language to contribute; this should influence our graduate curriculum
  - Team Work is becoming the rule not the exception (biology, physics, engineering, finance, social science, …, even math)

- This is still premised on having a core competence: in a discipline which has one
  - You have to know something substantial to contribute; this should influence our under-graduate curriculum
  - Is Computer Science such a discipline? Michigan thought Geography was not!
  - I question the value of an Interdisciplinary PhD (at Dalhousie the world's biggest: everyone's favourite niece?)
    - What's wrong with a Management PhD which has lots of IT or Sociology?

See www.pkal.org/collections/Vol4InterdisciplinaryResearch.cfm (2006)

IIC&C: Further Consequences

Need to know enough about the culture of other discipline or country

- publishing practices & styles: books vs papers vs proceedings
- citation rates differ wildly: "*Multidisciplinary journals tend to have low self-citation rates*." (ISI). See 2008 IMU report
- Finance, Economics (social science) rank a lot like Mathematics

Table 1. Comparison of the numbers of citations in different fields of science. Based on the data from *Science and Engineering Indicators 2004. National Science Foundation, May 04, 2004.*

Field	Average ratio of citation number to the number of citations in mathematics	1992		1994		1996		1997		1999		2001	
		number of citations	ratio to maths	number of citations	ratio to maths	number of citations	ratio to maths	number of citations	ratio to maths	number of citations	ratio to maths	number of citations	ratio to maths
Clinical medicine	78	475793	69	516665	78	554332	80	574859	90	584330	78	589762	76
Biomedical research	78	460148	67	518304	78	562361	81	572122	89	594596	79	568328	73
Biology	8	52535	8	57825	9	58649	8	58130	9	56981	8	57899	7
Chemistry	15	88010	13	96827	15	105960	15	105762	16	110927	15	109703	14
Physics	19	137922	20	141653	21	138417	20	131958	21	125968	17	120593	15
Earth/space sciences	9	55086	5	58818	9	71230	10	73507	11	83053	11	82614	11
Engineering/technology	5	32680	5	35189	5	33664	5	32958	5	34001	5	36809	5
Mathematics	1	6858	1	6631	1	6961	1	6418	1	7520	1	7794	1

- In some countries (UK, Oz) University funding is being driven by such "impact factor" metrics (MPUs, ERA) (know the enemy)
- Europe and the English-speaking world are diverging?

IIC&C: Further Consequences

- The Jury is still out, somewhat
  - good research, however performed, will usually rise to the top
    - "collaboration is associated with higher article citation rates, … research has suggested that this is, in part, related to the access to a larger social network and the increased visibility of research …" (2003, NZ study)

Jointly published by Elsevier Science Ltd, Oxford and Akadémiai Kiadó, Budapest

Scientometrics, Vol. 39, No. 2 (1997) 173–184

SCIENTIFIC COLLABORATION IN FINANCE DOES NOT LEAD TO BETTER QUALITY RESEARCH

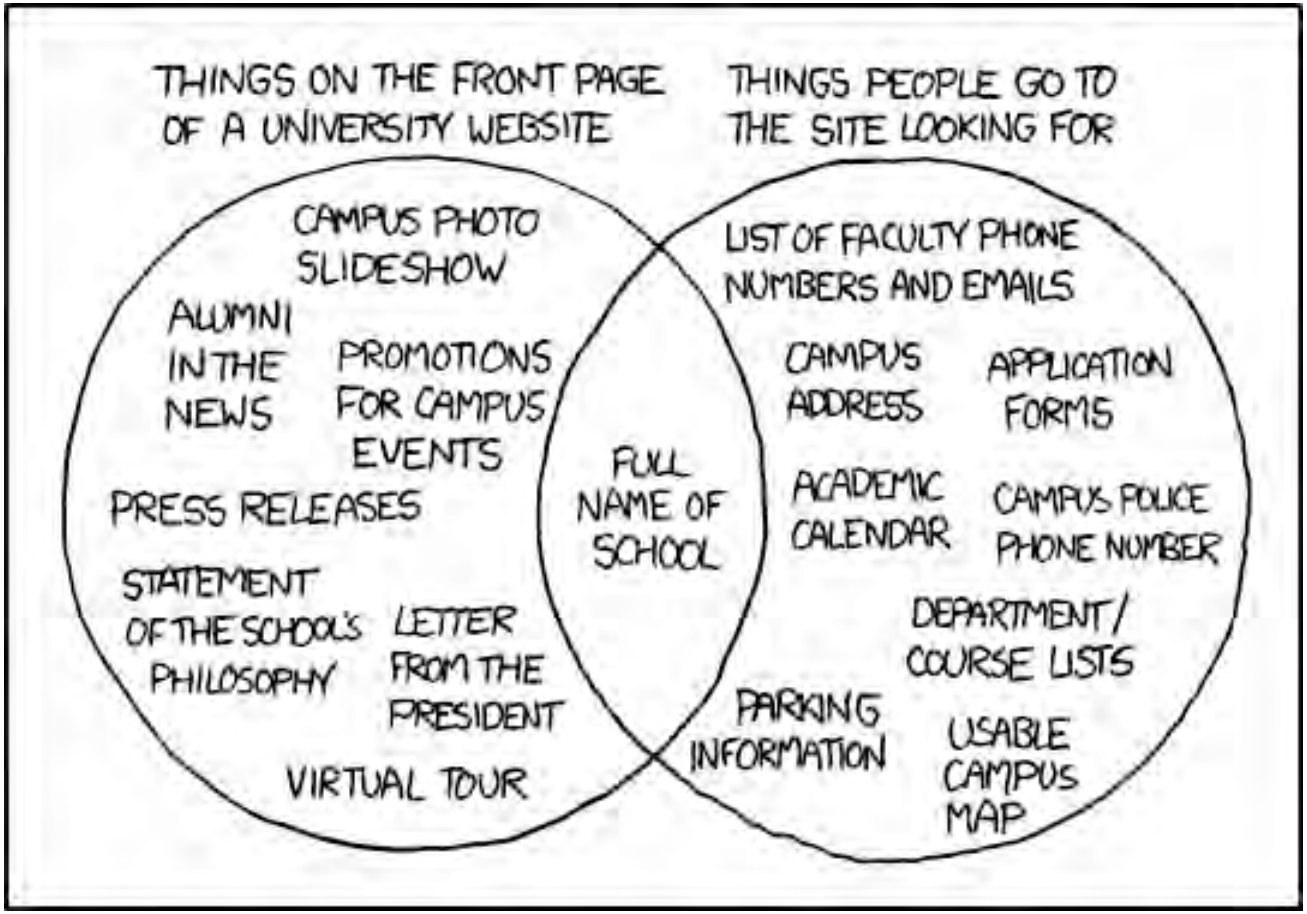
N. K. AVKIRAN

Hospitaly, Tourism, and Property Management, The University of Queensland, Gatton, Queensland 4345 (Australia)

(Received January 27, 1997)

The study reports an empirical comparison of quality of collaborative research with the quality of individual research. Quality of a paper is measured by the citation rate over the four years following the year of publication. Papers published in fourteen Finance journals between 1987–1991 are sampled. There is no significant difference between the quality of collaborative and individual research. Decision-makers should hesitate in interpreting collaborative research as a definitive sign of ability to produce better research.

Most of it isn't Rocket Science



Views of Recent Nobel prize winners

- They tend to understand STEM R&D a lot better than our own administrators or policy makers
- Some become fine administrators (David Baltimore?)

Steve Chu, Secretary of Energy, 1997 Laser cooling Nobelist

Bailey and Perlmutter at LBL, 2011

2007 and 2009 Physics Nobels

2007 German, Frenchman (Fert and Gruenberg) share award for work that lets computers, iPods and other digital devices store masses of data on ever-smaller disks

Mr. Gruenberg told reporters gathered at his institute that he was not too surprised to win the Nobel."Because I have received a lot of awards, I was often asked: *'When will the big award come?'* " Mr. Gruenberg said. He said the prize money would let him do research "*without having to apply for grants for every tiny bit*."

2009 A pioneer in fiber optics and two scientists who figured out how to turn light into electronic signals -- work that paved the way for the Internet age

- Charles K. Kao, Willard S. Boyle, George E. Smith
- Kao was VC at CUHK
- Boyle CCD co-discoverer, was a Nova Scotian at its heyday

"What the wheel did for transport, the optical fiber did for telecommunications," - Richard Epworth, 1960s co-worker of Kao at Standard Telecommunications Laboratories in Harlow, UK

2009 Australian Medical Nobel Elizabeth Blackburn (1948-)

"My specific aims didn't have 'discover telomerase'. I didn't even know I wanted to discover telomerase," she said

- in **The Australian** of February 24, 2010.

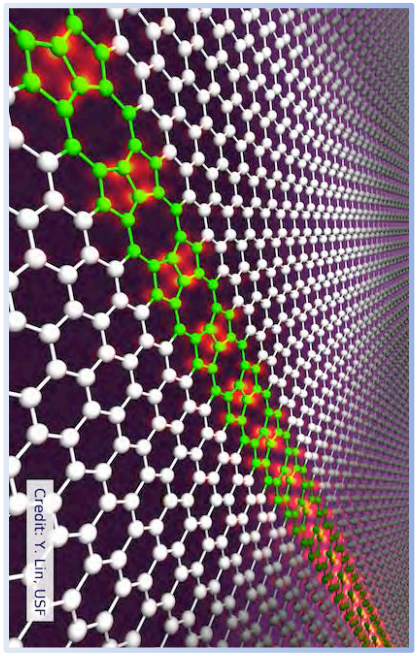
- In a follow up piece **on collaboration** she comments:

"My feeling is not to get too cross-disciplinary and shallow and spread all over the place too quick."
Blackburn tells the HES while visiting Monash University, where she is a distinguished visiting professor. "One needs to be able to bring something very substantive to the table because I can see the temptation would be to try to be overly generalised and shallowness would be the consequence."

2010 Physics Nobels: Andre Geim (L) &Konstantin Novoselov (R)

In that regard, this year's prize could be considered an anomaly. In the past, a few prizes have quickly spotlighted discoveries that upended the prevailing theory; others have recognized advances that over decades had led to ubiquitous applications. This year's prize, by contrast, honors physics that by all accounts is beautiful but not revolutionary.

"You don't need a new theory" to understand **graphene**, says Jeroen van den Brink, a theorist at the Institute for Materials Sciences at the Dresden University of Technology in Germany. At the same time, it celebrates the potential for applications yet to come. "Will this really come into the market?" Kim says. "I think it's really difficult to say." Still, everyone interviewed by Science says Geim and Novoselov thoroughly deserve the prize.



Still in Its Infancy, Two-Dimensional Crystal Claims Prize *Science* 8 October 2010: Vol. 330. no. 6001, p. 159. (Graphene)

2011 Australian Physics Nobel: Brian Schmidt

The Nobel Prize in Physics was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"*.

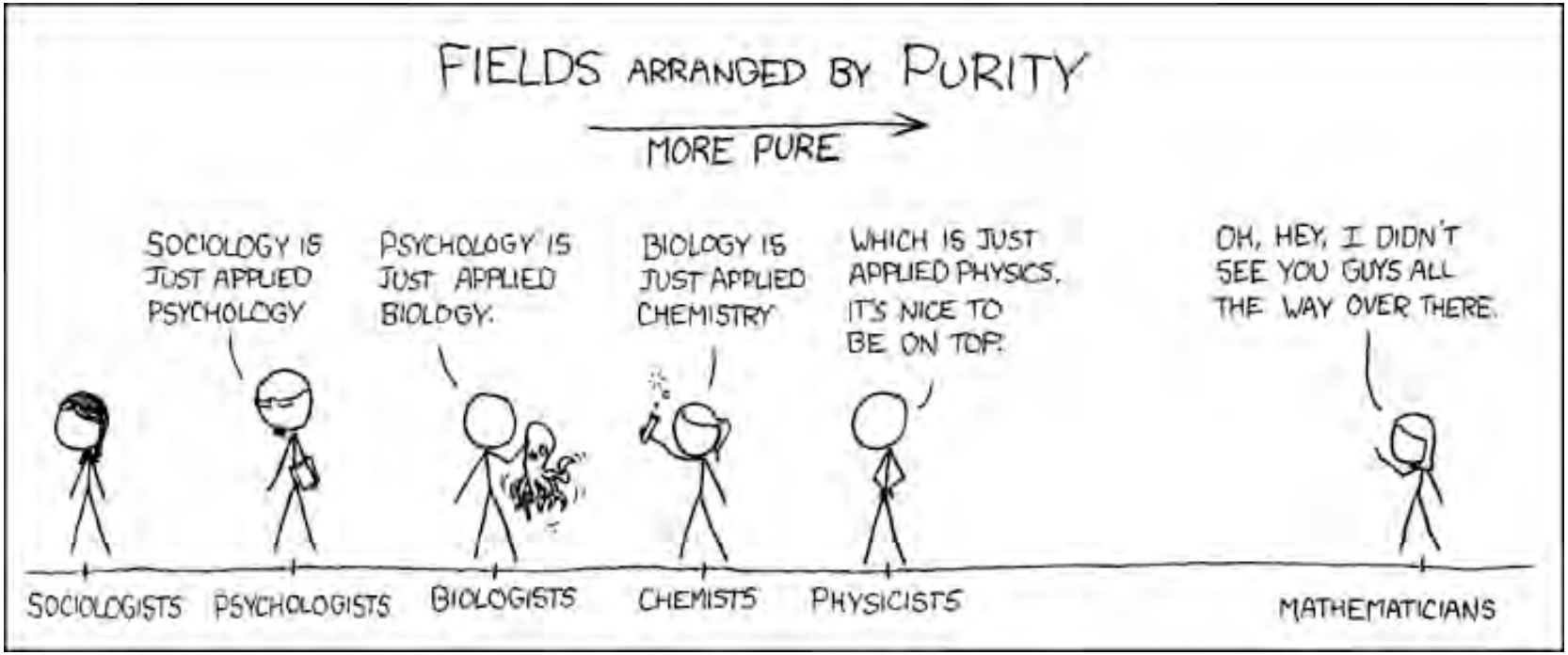
- In February at the AMSI **forum of national educators** in Canberra, **Brian Schmidt** went so far as to warn that Australia's resource boom was threatened by a lack of highly-trained engineers, **saying**:

"Too many kids who are willing and able to excel at maths are taught by teachers without the competency required to teach the subjects they are teaching."

"It seemed too crazy to be right so we were a little scared.
"I always look to Einstein because he got a lot right. Einstein's idea that space itself has an energy is the simplest reason that the universe could be speeding up."

Brian Schmidt gave $100,000 of his prize money to the AAS for Primary Connections

Some of it is Rocket Science

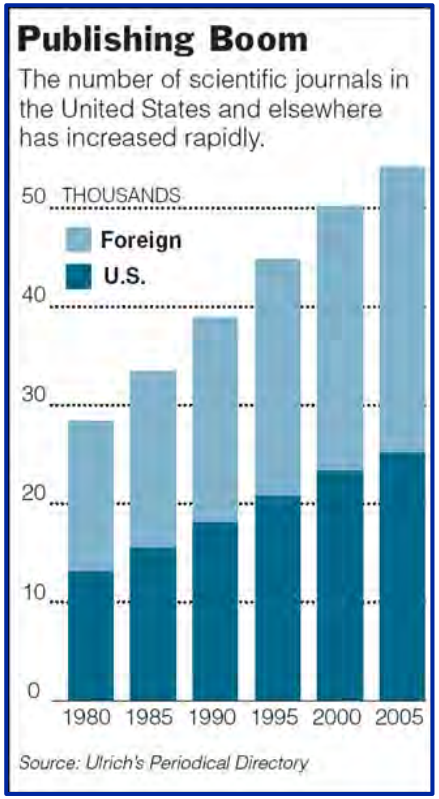


Cognitive Styles Matter

Changing Cognitive Styles

- ✓ Stroop effect
- ✓ “Strategic reading”
- ✓ Wolfram Alpha

16.23 petaflop Sequoia at LLL

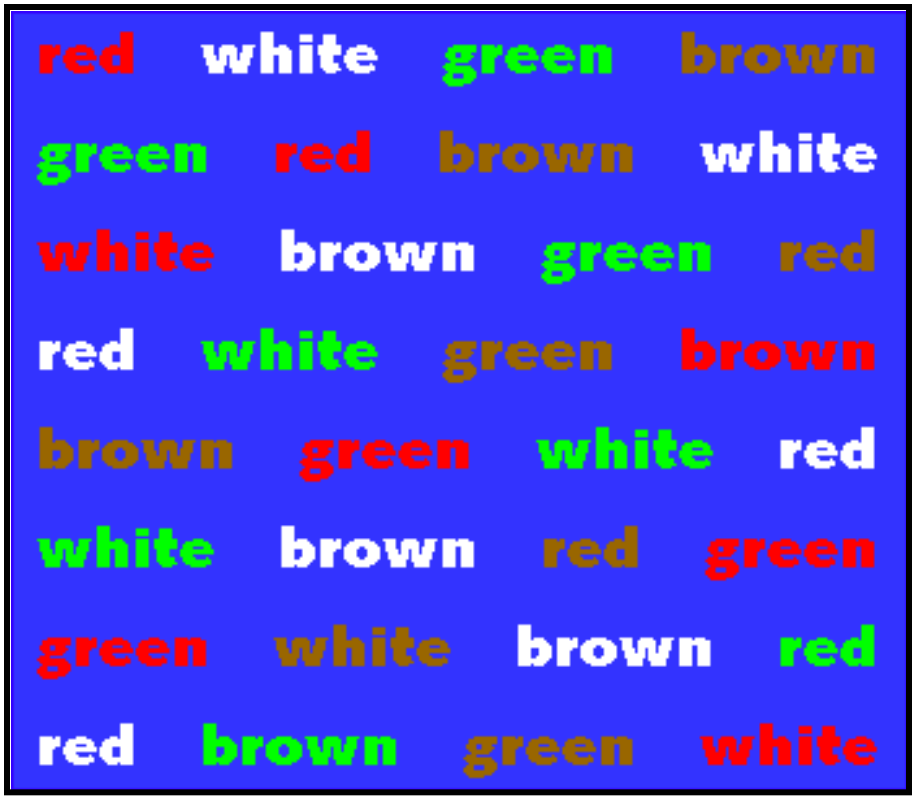


Moore’s Law is Still in Effect

- ✓ The media will look very different in ten years
- ✓ Human beings will not and have to learn to cope

Changing User Expectations

What is attention? (**Stroop** test, 1935)



1. Say the **color** represented by the **word**
2. Say the **color** represented by the **font** color

(young) multi-taskers perform #2 easily and are (too) good at suppressing information?

Hypnotism works: *Sleight of mind*

Acknowledgements: Cliff Nass, CHIME lab, Stanford (interference and twitter?)

Other Cognitive Shifts

Harwell 1951-1973

Science Online August 13, 2009

Strategic Reading, Ontologies, and the Future of Scientific Publishing

Allen H. Renear* and Carole L. Palmer

The revolution in scientific publishing that has been promised since the 1980s is about to take place. Scientists have always read strategically, working with many articles simultaneously to search, filter, scan, link, annotate, and analyze fragments of content. An observed recent increase in strategic reading in the online environment will soon be further intensified by two current trends: (i) the widespread use of digital indexing, retrieval, and navigation resources and (ii) the emergence within many scientific disciplines of interoperable ontologies. Accelerated and enhanced by reading tools that take advantage of ontologies, reading practices will become even more rapid and indirect, transforming the ways in which scientists engage the literature and shaping the evolution of scientific publishing.

✓ Potentially hostile to many research patterns

Interdisciplinarity and Collaboration: Final Conclusion

- A pretty compelling 2007 study

Originally published in *Science* Express on 12 April 2007
Science 18 May 2007:
Vol. 316. no. 5827, pp. 1036 - 1039
DOI: 10.1126/science.1136099

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Reports

The Increasing Dominance of Teams in Production of Knowledge

Stefan Wuchty,[1*] Benjamin F. Jones,[2*] Brian Uzzi[1,2*†]

We have used 19.9 million papers over 5 decades and 2.1 million patents to demonstrate that teams increasingly dominate solo authors in the production of knowledge. Research is increasingly done in teams across nearly all fields. Teams typically produce more frequently cited research than individuals do, and this advantage has been increasing over time. Teams now also produce the exceptionally high-impact research, even where that distinction was once the domain of solo authors. These results are detailed for sciences and engineering, social sciences, arts and humanities, and patents, suggesting that the process of knowledge creation has fundamentally changed.

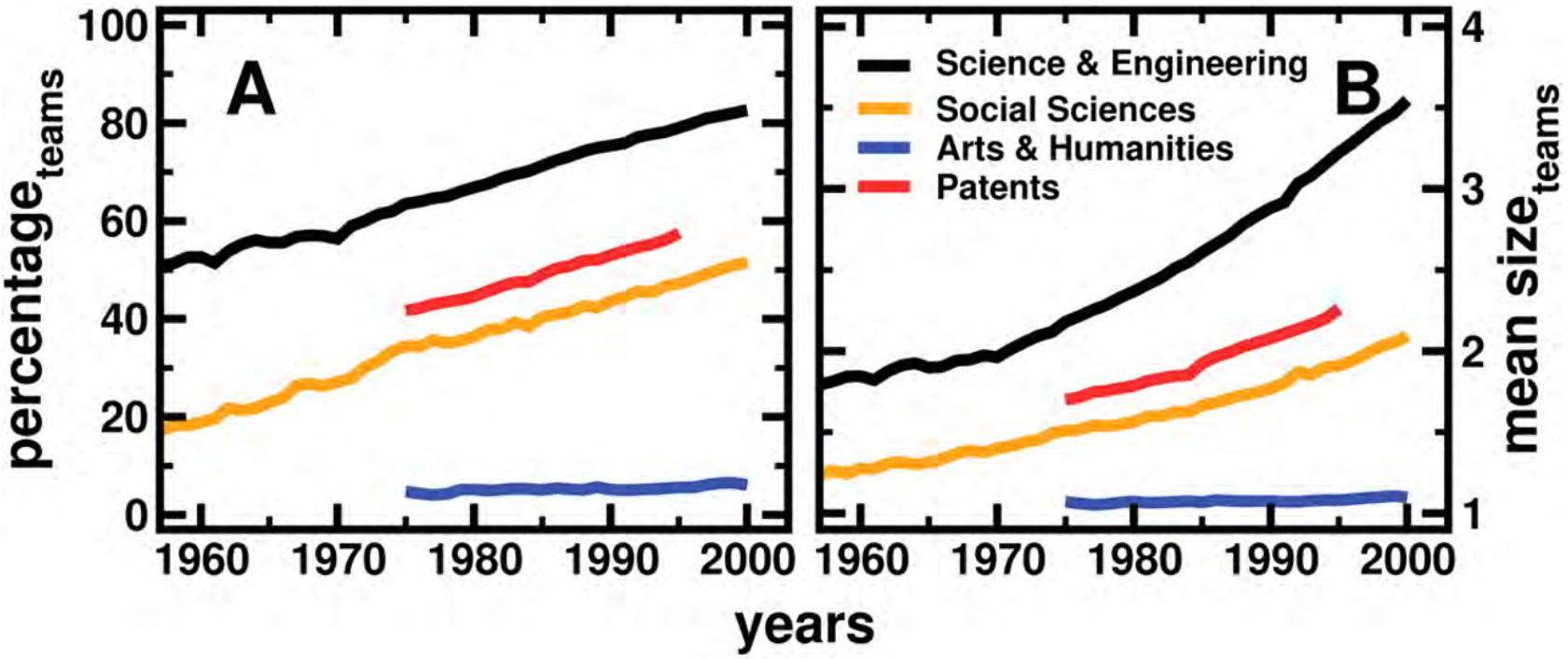
"An acclaimed tradition in the history and sociology of science emphasizes the role of the individual genius in scientific discovery (*1*, *2*). This tradition focuses on guiding contributions of solitary authors, such as Newton and Einstein, and can be seen broadly in the tendency to equate great ideas with particular names, such as the Heisenberg uncertainty principle, Euclidean geometry, Nash equilibrium, and Kantian ethics. The role of individual contributions is also celebrated through science's award-granting institutions, like the Nobel Prize Foundation (*3*)."

I&C: Final Conclusions

		Increasing team size		RTI > 1 (with self-citations)		RTI > 1 (no self-citations)	
	N_{fields}	N_{fields}	%	N_{fields}	%	N_{fields}	%
Science and engineering	171	170	99.4	167	97.7	159	92.4
Social sciences	54	54	100.0	54	100.0	51	94.4
Arts and humanities	27	24	88.9	23	85.2	18	66.7
Patents	36	36	100.0	32	88.9	-	-

Trends for individual fields are presented in table S1. In the sciences, areas like medicine, biology, and physics have seen at least a doubling in mean team size over the 45-year period. Surprisingly, even mathematics, long thought the domain of the loner scientist and least dependent of the hard sciences on lab scale and capital-intensive equipment, showed a marked increase in the fraction of work done in teams, from 19% to 57%, with mean team size rising from 1.22 to 1.84. In the social sciences, psychology, economics, and political science show enormous shifts toward teamwork, sometimes doubling or tripling the propensity for teamwork. With regard to average team size, psychology, the closest of the social sciences to a lab science, has the highest growth (75.1%), whereas political science has the lowest (16.6%). As reflected in Fig. 1A, the humanities show lower growth rates in the fraction of publications done in teams, yet a tendency toward increased teamwork is still observed. All areas of patents showed a positive change in both the fraction of papers done by teams and the team size, with only small variations across the areas of patenting, suggesting that the conditions favoring teamwork in patenting are largely similar across subfields.

Fig. 1. The growth of teams



S. Wuchty et al., Science 316, 1036 -1039 (2007)

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Science
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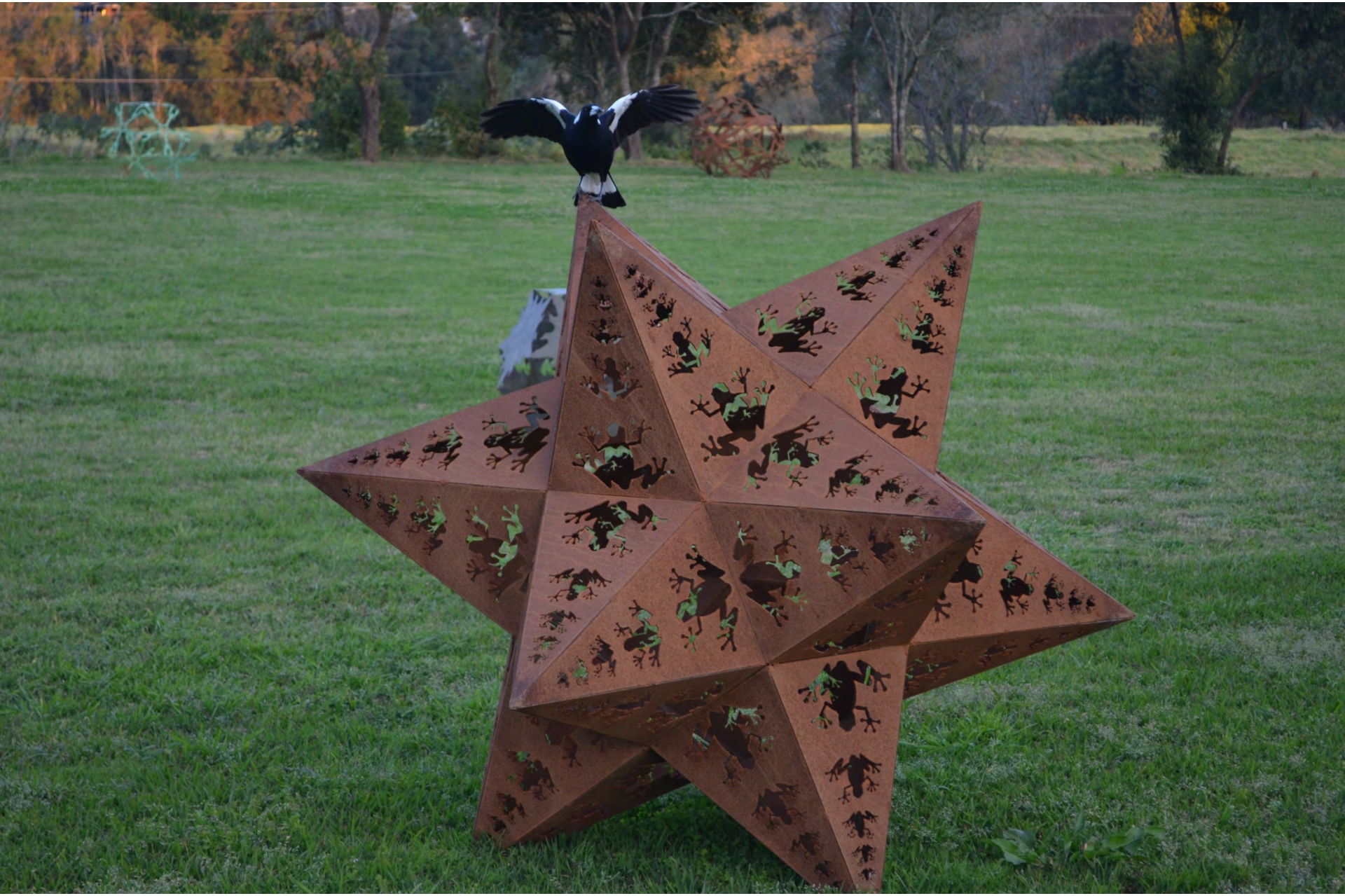
Mathematics in the Barrington Tops



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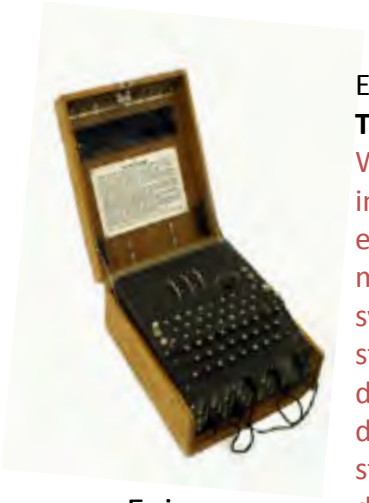
AAAS-Science http://sciencenow.sciencemag.org

- keep up on trends and policy issues



Enigma

Editors' Choice: Highlights of the recent literature 17 August 2012, 337 (6096)

The Cost of Improvement Brad Wible

With increased emphasis on the role of science and technology in economic prosperity come increased efforts to improve science education. In the United States, science-focused education efforts occur on a backdrop of broader efforts to improve public education by using standardized tests of student achievement, largely limited to literacy and math. Because low test scores often come with steep consequences, the pressure to "teach to the test" can corrupt the system and undermine the very educational processes that are being monitored. Indeed, research has shown that high-stakes standardized tests focused on literacy and math in primary school can lead to decreases in the instructional time dedicated to other topics such as science. Maltese and Hochbein studied U.S. high schools in Indiana and found that despite school-level improvement of some schools on measures of math and literacy as reflected on a statewide standardized test used for evaluating schools (ISTEP), student-level performance in those improving schools did not demonstrate improvement in literacy or math on a separate, widely used college-entrance examination (ACT). Furthermore, school-level improvement on ISTEP math and literacy was generally associated with lower individual student-level science achievement on ACT. *J. Res. Sci. Teach.* **49**, 804 (2012).

Nature http://www.nature.com or New Scientist, THES, Scientist, Science Weekly, Science Daily, American Scientist, … the Edge, TED

My morale has never been higher than since I stopped asking for grants to keep my lab going.
Robert Pollack, Columbia biologist, on "the crisis in scientific morale", Sept. 19, 1996 at GWU symposium *Science in Crisis at the Millennium*. (p. 1805, 27/09/96 Science)

What are the implications for

- Australian Mathematics?
- Australian (Social) Science?
- This University?
- Universities?
- Australia?

'BE CAREFUL'! ALL YOU CAN TELL ME IS 'BE CAREFUL'?"

Moore's law This picture is worth 100,000 ENIACs

The number of **ENIACS** needed to store the 20Mb TIF file the Smithsonian sold me

THANK YOU