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PERSPECTIVES

Interdisciplinary Materials Research: The Reluctant Reformer of Western Science

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The Challenge to the Materials Research Community

The facets of a gem are cut at specific angles to produce combinations of reflection and transmission of the beautiful colors we desire. This is a "reflective" article about facets. It looks historically at the origins of the field of materials research (not the discipline of materials science) and after reflection, draws out the enormous significance of this kind of focusing of human learning for societal objectives. This is a key distinction from the artificial disciplines of post-Renaissance Western education. It involves "synthesis" instead of further fragmentation. I have been championing this cause of understanding the epistemological significance of this innovation, the birth of interdisciplinarity, within the materials community. After 2–3 years of proselytizing, I find that a few materials researchers are indeed understanding the responsibility for all of us to champion the cause of I^3, the **I**ntegrated **I**nterdisciplinary **I**nter-institutional aspects of learning. And with it to take a leading role in representing "science" to the world. For good or ill, physics is fast fading as the poster child of science; biology may or may not attain that position. The materials star is high right now. It falls to us to restore science to a position in which it is better understood, more participatory, and more genuinely connected to society. This is the case presented in this article!

Historical Background

Interdisciplinary Materials Research, historically speaking, is the turning point in the fragmentation—the fissiparous imperative—in the life of Western Science. Unfortunately, however, materials researchers suffer from the syndrome called the "colonized peoples' mindset." They have been colonized by physicists and chemists (into which families most were "born") to the point of forgetting that it is **their** science (materials) which is **much older**, much more valuable, much more understandable, and much more reliable, than that of the colonizers of abstract physics, chemistry and biology: ("PCBs"?) To put it another way, materials is a primary human "science," a multi-level way of knowing, alongside agriculture and health sciences. These can be touched, felt, experienced, used by every person, as compared to the much more **abstract** sciences of biology, chemistry, and physics, intelligible to perhaps a 10% minority, and used by many fewer. Indeed as depicted in the accompanying chart, materials is a unique contemporary **gateway** to all of technological **culture**, to **education** in science, engineering, and mathematics (hence the acronym—MAGSTEM, **M**aterials **G**ateway to all **S**cience, **T**echnology, **E**ngineering and **M**ath), and of course, to **research**. The total failure—in spite of the expenditure of a few billion dollars by just the NSF (U.S. National Science Foundation), and in spite of thousands of articles by well-paid teachers and well meaning journalists—to convey even the rudiments of the basics of abstract science to the general public, is simply due to the inexorable fact that fewer than 10% of humans have the capacity to deal with abstractions. You cannot, repeat *cannot,* teach the masses science via the mind alone: it needs all the other senses. In case you think I overstate the failure, I refer you to the detailed documentation provided by the Annenberg project of the failure of 90% of Harvard and MIT graduates in one of many unbelievable examples. To get the impact of the real data, the reader should view the detailed TV clips, where MIT and Harvard graduates explain (winter and) summer as being caused by a closer approach by the sun in summer!!

MATERIALS……

- **AS THE GATEWAY TO (ALL) SCIENCE TECHNOLOGY ENGINEERING & MATH**

	FOR	C = In Culture
MAGSTEM	FOR	E = In Education
	FOR	R = In Research

Materials, the quintessential "touch science," as the "gateway science" to the public.

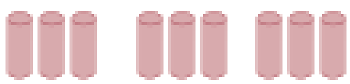
The evolution of these **abstract** "disciplines" in Western culture followed the path shown in the accompanying cartoon, towards increasing fission and segregation into so-called disciplines ending up with the "discipline" (i.e., department) and "college" architecture of the Western University. This structure had two fatal flaws. Each college was a loose aggregation of departments with a vague similarity or affinity to each other, but with no formal vehicles for interaction among them. Each department gradually developed into a water-tight, inward-looking, stove-pipe structure which kept all knowledge inside and filtered all other knowledge out (as characterized in the accompanying chart). This emerging absurdity passed largely unchallenged for a couple of hundred years. About 1950, two philosophers who understood the obvious deficiency of the systems converged on it (see boxes). Ortega y Gasset noted that this existing fragmentation and specialization was dysfunctional and must be balanced in the future by the "genius" for integration. Alfred North Whitehead commented on the dire effects of this system: "At this moment scientists and skeptics are the leading dogmatists;" and he shows how this results in a situation in which "Advance in detail is permitted; fundamental novelty is barred." This is confirmed daily in the peer-reviewing for journals by the "paradigm-protecting-editorial-police," who, having totally failed to filter out junk science (as demonstrated by the recent stream of cheating scandals **in** mainstream science), certainly manage to filter **out** all the exciting new data/ideas which come from outside their own stove-pipe!

1600-1900 FISSION OF KNOWLEDGE BY UNIVERSITY STRUCTURE

Universities grow into Ivory Towers
Consisting of isolated Silos

By 1950

Education/research is in isolated depts. in isolated colleges



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The coming of the discipline-bound University.

> *The momentum which impels investigation to dissociate indefinitely into particular problems, the pulverization of research, makes necessary a compensative control – as in any healthy organization – which is to be furnished by a force pulling in the opposite direction, constraining centrifugal science into a wholesome organization …*
> *The need to create sound syntheses and systemization of knowledge … will call out a kind of scientific genius which hitherto has existed only as an aberration: the genius for integration.*
> ***José Ortega y Gasset,** Mission of the University*

> *The universe is vast. Nothing is more curious than the self-satisfied dogmatism with which mankind at each period of its history cherishes the delusion of the finality of its existing modes of knowledge. Skeptics and believers are all alike. At this moment scientists and skeptics are the leading dogmatists. **Advance in detail is admitted: fundamental novelty is barred.***
> ***A.N. Whitehead,** in Essays in Science and Philosophy*

At about the same time (1950–1955), this feeling among the philosophers was mirrored in the thoughtful leadership of industrial managers in the U.S. Under the leadership of W. O. Baker, then Vice President for Research at Bell Labs, they took on the task—which no university had dared to accept—of doing something about infinite subdivision. Being practical people, they also realized that the very best of intellectual and philosophical arguments carried little weight especially in academic circles…, and that financial "incentives" might work best!!

Thus was born, through the Department of Defense (DoD) of the U.S., and its most basic research agency called ARPA (Advanced Research Projects Agency), the so called I.D.M.R.L.s, "Interdisciplinary Materials Research Laboratories." The incentive was amazingly generous: massive dollar volumes and long-term contracts. Consider: in 2004 dollars the average grant to an individual professor from most agencies ranges from around US$100K–$150K. Yet half a dozen of the original dozen I.D.M.R.L.s have been continuously funded for over 40 years at the level of US$3–5M each per year in several universities. Some University I.D.M.R.L.s have received nearly a quarter of a billion dollars!! They were supposed to exemplify interdisciplinarity. Yet to date, there has been no study evaluating this risk taken by comparing the degree of interdisciplinarity achieved against that of other organizations on which no such largesse was bestowed.

One can date with precision, 1960, as the turning point or change—albeit only a second derivative change—in the fission-fusion tug of war among disciplines referred to by Ortega y Gasset. This historic event was triggered by Baker (and Suits) and executed by ARPA in a wholly American setting. The start of the DoD IDMRLs was the equivalent of Luther triggering the Reformation by nailing his 95 theses to the Cathedral door in Wittenberg. The birth of interdisciplinarity was an American affair. Europe was at least a decade behind. This is interestingly illustrated in the recent book from Europe by R. W. Cahn "The Coming of Materials Science" in which this radical administrative innovation which drove disciplinary integration, the signature of the materials field, is not even mentioned. It is, in a way, subsumed into the content fluctuations within one discipline—materials science and its relationship to metallurgy.

But academic "disintegration" and fission had also been transmitted to other dimensions of the research enterprise. The theoretical foundation for the errors lay in the ruling R & D theory (in 1960) called the "linear" theory which was certainly held with dogmatic clarity by the vast majority of the academic community. It went thus:

Basic science (done largely at universities) *leads to*
⇓
Applied Science (done in industry research labs and in lesser rank engineering schools) *which leads to*
⇓
Technology (done in industry) *which leads to*
⇓
Prosperity (for society which is then induced to invest more in basic science).

This schema led to an isolation of the universities from the reality of applications in this vertical dis-integration of knowledge.

This linear theory was wrongly attributed to Vannevar Bush and his classic report to the President "Science: The Endless Frontier." That is certainly a misreading of Bush, as Shapley and Roy (1985) showed in our book "Lost at the Frontier." But it can be seen that the adoption of this flawed interpretation by the U.S. science establishment was a major loss to the country. Moreover, it was a blow to a wholesome development of science, since the basic science "solutions" supposedly studied in academia were cut off from the real world's problems.

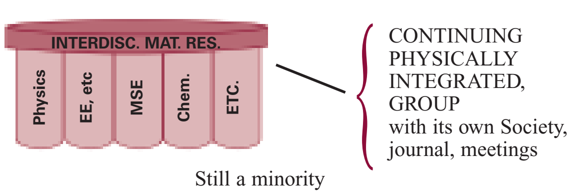
Penn State University—not funded as an ARPA IDMRL—nevertheless set up the world's first Interdisciplinary Materials Research Laboratory, being independent of any agency or program, and having none of these biases. From the lab's inception in 1962, we set up an "Industrial Coupling Program"—with a dozen industries, not basically for money but to learn from industry of the most compelling problems encountered by society and industry, so we that could work on the basic leads to aspects of those problems. Our model was that of Bell Labs—the premier laboratory and model for America's most effective science, as described by Cahn. This alternative to the linear theory, "**applications-driven** basic science," was also the guiding principle of America's first national research agency supported by **public** funds—the Office of Naval Research (ONR).

Thus was born the golden age of materials research. On the one side, the **attempt** at financial-incentive triggered interdisciplinarity on campus, and on the other side, applications-driven **integrative** (with industry) university research.

The image of what each of the interdisciplinary institutions attempted to become, a genuinely voluntary, physically integrated, continuing, group of faculty, is outlined in the accompanying chart. Soon there developed a new community with its own centripetal forces such as meetings, Societies, Journals, etc. This development spanned about 30 years from 1960–1990. By 1980 or so, it was clear that materials research was "arriving," with a seat at the table of science-organization. Materials was suddenly "in." Ceramic engines, superconductors, CVD diamonds, bucky balls and nanotubes were getting the "buzz," displacing supernovae and supercolliders. Slowly, physics and astronomy were being displaced.

1960–≈1990

- **INTERDISCIPLINARY LABS, GROUPS, STRUCTURES SPROUT ALL OVER. IN "MATERIALS" FIRST, THEN "ENVIRONMENT", "BIOTECH", etc.**



The emergence of genuine integration across disciplines.

But not all was going well; by the late 1990s a curious backlash was in full swing. A dangerous **dis**-integration was now starting to occur. Since "interdisciplinarity" was such a desirable title if not a practice, every discipline set about to expropriate the title of "interdisciplinarity" to itself—each department (e.g., chemistry or physics or electrical engineering) soon realized the value of claiming that it was doing "interdisciplinary" work, albeit within the discipline!!! "Interdisciplinarity" in 2005 stands in danger of becoming icing on the cake (as depicted in the final chart) on top of each stove-pipe discipline, with no penetration into the main framework of its thinking or practice.

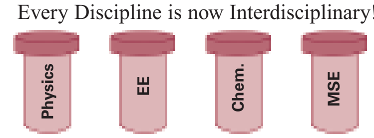
Admiral Gaffney, then head of all Naval Research, recounts that 50 years after the linear-theory conceptualization, these two "theories" of basic research and the resulting practices had diverged widely. He contrasts this with Shapley and Roy's model and Stokes' model of applications-driven work. He contrasts ONR's manager-decision process with the so-called "peer-review" process which, by general agreement, is strongly biased against genuine innovation. Although the industrial world had in **part** toyed with the "linear theory" for its "basic research" laboratories, by 1994–1995, all of industry, worldwide, decisively and totally abandoned it. Unfortunately, American universities are now placed in the schizophrenic posture of having to do applications-driven research in institutions still unwilling to abandon the now fully discredited linear theory which is built into their structures, and to hand off their results across the chasm between University and industry cultures.

DANGEROUS DIS-INTEGRATION NOW STARTING 1995–2005

SINCE 1995 WORLD INDUSTRY HAS 100% ABANDONED LINEAR THEORY AND ITS RESEARCH IS ALL INTERDISCIPLINARY BUT IN THE UNIVERSITY

NEW TREND IS "VIRTUAL" INTERDISCIPLINARITY

Every Discipline is now Interdisciplinary!!!



The backlash: the re-emergence of discipline-power and the expropriation of the term "interdisciplinarity."

There are clear directions for desirable change. Such changes have been made worldwide in industrial research. Academic institutions all over the world can learn from the U.S. advances and its mistakes. How this re-invention can be brought about in academia is unclear, but it will certainly be the result of major economic dislocations which will bring a dose of reality to academia.

If Integrated, Interdisciplinary, Inter-institutional (I^3) research (as reported by Roy [2000] in a book length report of the International Conference on this very topic), is the way forward, it will require the thoughtful and committed efforts of all materials researchers, in all countries, who to date have not paid much attention to such matters. I hope that materials researchers who read this article, especially those in senior positions in academia or government, and especially those outside the U.S., will indeed pay attention to these societal matters, and thereby seize the leadership of national and international science policy.

Further Reading

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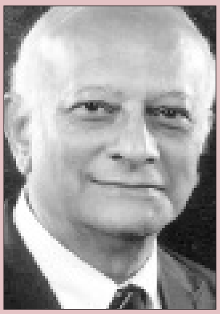

Rustum Roy has been the national champion of interdisciplinarity in the U.S. He started the first truly interdisciplinary, "under-no-department" degree in materials in 1959. This is the oldest such in the country and has produced more graduate degrees than any other. He started and directed Penn State's Materials Research Laboratory (MRL), the first such interdisciplinary lab in the world. In 2003 the ISI (Phila) rated it the #1 lab in the world on the basis of highly cited scholars. Between 1967–1982 he started and maintained the Materials Research Society in Penn State's MRL, its 1st meeting being held there in 1973. He created parallel interdisciplinary institutions in the wider field of Science, Technology, and Society from 1974–present.

His wider interdisciplinary interests are reflected in his activities, extensive writing and recognition in Science Policy, and Religion and Technology where he has espoused the same integrative paradigm.

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