Can Industrial Physics Avoid Being Creatively Destroyed?

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“Future of Research in Industrial Laboratories”
Predictions

- Yes, in the sense that physics/physicists will always make vital contributions to innovation-driven business success in some companies and industries.

- No, in the sense that technologies, industries, and companies will continue to evolve (at an accelerating pace), and industrial physics/physicists may be prime fodder for creative destruction if they do not continuously adapt and prove their business value.

*Industrial physics will be far more diverse, dynamic, and non-academic in the future.*
Economists love maximum efficiency. But people don’t. We want market efficiencies to make us richer, but we don’t like what an efficient market feels like.”

“The Sink-or-Swim Economy,”
NY Times, June 8, 2003

Creative Destruction
Joseph Schumpeter (1942)
• “Revolutionizing the economic structure from within”
• Driver of industrial innovation, evolution, efficiency

Industrial Physics: Victim of its Own Success?
Two Key Conclusions:

- Tension between continuity and discontinuity
- Mental models often limit creativity and innovation
Main Themes of This Talk

- Insights from Complex Systems Research
- Evolving Mental Models for Industrial R&D
- Examples from Ford/Automotive R&D
- Challenges to the Broader Physics Community
The Emerging Science of Complex Systems

- Multiple “things” interacting in “interesting” ways
- Growing consilience among disparate fields
  - From physical sciences to social sciences
  - Key insights from biology, computer science, economics
- Relevant to an increasingly complex world
  - Global economy and environmental challenges
  - Increasing interconnectedness and pace of change
  - Spread of capitalism and democracy
  - Increasing socioeconomic inequities
  - Increasing threats: terrorism, energy security, …

*Thanks to University of Michigan’s Physics Dept. and Center for the Study of Complex Systems!*
Roots of Complex Systems Research

- **Physical Sciences**
  - Nonlinear dynamics, chaos
  - Nonequilibrium thermodynamics
  - Random manifolds (spin glasses)
  - Self-organized criticality

- **Biology**
  - Evolution
  - Population dynamics, ecology
  - Origin of life
  - Animal aggregation
  - Neuroscience (consciousness)
  - Protein folding/gene expression
  - Epidemiology

- **Economics**
  - Game theory
  - Bounded rationality
  - Increasing returns ("lock in")
  - Econophysics
  - Behavioral economics

- **Mathematics**
  - Catastrophe theory
  - Fractal geometry
  - Networks ("small worlds")

- **Organizational Science**
  - Logistics
  - Systems dynamics

- **Psychology**
  - Group Dynamics
  - Gestalt

- **Computer Science**
  - Cybernetics
  - Neural networks
  - Artificial intelligence/life
  - Cellular automata
  - Evolutionary programming (GA)
  - Information theory
  - Computational complexity
Complexity: A Bridge Between the “Two Cultures” of Physics & Business?

- Expanded/Balanced Perspective

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<thead>
<tr>
<th>Reductionist</th>
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</thead>
<tbody>
<tr>
<td>Linear</td>
<td>↔</td>
<td>Nonlinear</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>↔</td>
<td>Nonequilibrium</td>
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<td>Mechanical</td>
<td>↔</td>
<td>Organic, Evolutionary</td>
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<tr>
<td>Predictable</td>
<td>↔</td>
<td>Contingent, Emergent</td>
</tr>
<tr>
<td>Optimizable</td>
<td>↔</td>
<td>Robust, Adaptive, Strategic</td>
</tr>
<tr>
<td>Centralized</td>
<td>↔</td>
<td>Distributed, Self-Organized</td>
</tr>
<tr>
<td>Quantitative</td>
<td>↔</td>
<td>Qualitative, Patterns</td>
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Dominant worldview in physics and established business operations

More useful for understanding, leading, and/or adapting to changes in business environment and industrial R&D!
“I can calculate the motion of heavenly bodies, but not the madness of crowds.” - I. Newton

“Imagine how difficult physics would be if electrons could think.” - M. Gell-Mann
Efficiency vs. Creativity: Landscape Metaphor

Exploitation = local optimization (requires efficiency)

Exploration = global search (requires creativity)

Landscape Is Itself Changing!
Discontinuity
Paradigm Shift
Co-Evolution

Different roles for physics/physicists
Prevailing, But Flawed Mental Models for R&D

Static:
Basic vs. Applied

Dynamic:
Linear Reservoir Model

First APS President H. Rowland’s “Plea for Pure Science,” 1883

V. Bush: “Science: The Endless Frontier” 1945

Basic Research → Reservoir of Knowledge → Applied Research → Technology

Commercialization implicit!
Limitations of Linear Models

- Problem is **not** one dimensional:

  - **Quest for Understanding** (Basic, Science)
    - Bohr, Einstein
    - Pasteur, Langmuir, Bardeen
  - **Consideration of Use** (Applied, Technology)
    - Edison, Ford

- Flow is **not** unidirectional:
  - Steam Engine (Applied) → Thermodynamics (Basic)

Science and Technology!

Most fertile ground for industrial physics?

"Pasteur’s Quadrant"
D. Stokes (1997)
Complex Dynamical Interactions

New Knowledge

Consideration of Use

New Capabilities

Engineering

New Questions

Industry benefits most from strong alignment and tight feedback:
*Individuals, teams, and/or external partnerships*
Ford Example: “Atoms to Engines”

Deeper Understanding

Virtual AI Castings (John Allison, et al.)

More “Useful”

Bottoms-Up Materials Theory & Computation (Chris Wolverton, et al.)
Why Discrepancy for Relative Stabilities of $\theta/\theta'$ ?!

Vibrational Entropy!!!  
Wolverton and Ozolins, PRL 86, 5518 (2001)
Significant Impact on “Downstream” Models

First-principles calculations

Computational Thermodynamics

\[ f_{\theta'}(x,T) \]

Yield Strength Model

Thermal Growth Model

Both Extremely Successful!

Unexpected temperature-dependence of free energy
Tech Transfer and Commercialization

- Focus on most promising market opportunities very challenging
- Simple mental models (linear path, “over the wall”) inadequate
- Biological analogies (e.g., adaptive networks) may be helpful
  - Complete paths matter, not sequence in which they develop
  - Most promising pathways need to be reinforced at expense of others
Ford Active Night Vision System
(W. H. Weber, J. T. Remillard, et. al)
Once the technology is close to implementation, the hard work begins!

- Marketing
- Cost Reduction
- Integration with Other Systems
- Packaging
- Regulatory Compliance
  
...
Automotive OEM View of R&D Enterprise

Frontiers Of Knowledge

Nanoscale Computation Biology Complexity . . .

Research

Academic Government Other Companies

Development

Supply Base

Internal

Technology Needs/Wants

Powertrain Materials Safety Electronics Emissions . . .

Business Units/Products

Internal

Strategic/Resource/Process Constraints

Regulatory/Manufacturing/Infrastructure/Financial/Competitive Concerns

"Firefights"

Other Companies

JDAs
General Comments on Industrial Research

- **Generalizations are dangerous!**
  - Most important thing is for R&D organization to be aligned with overall business strategy
  - Innovation and R&D may be more important than ever in providing competitive advantage → approaches to industrial research are becoming increasingly diverse (not just big company vs. small, mature vs. start-up))

- **Physicists face particularly strong challenges & opportunities**
  - No entitlements, but always a need for talented, flexible, creative, and persistent people who can solve known problems and/or lead the way through technological uncertainty and change
  - Value of “pure” physics research likely to be increasingly questioned, but physicists who understand and can cope with the two cultures of physics and business and can interact/collaborate effectively with experts in other fields have tremendous opportunities
**Academic Perspective**

“Basic research is like shooting an arrow into the air, and where it lands, painting a target” - H. Stine

University physics departments produce master archers!

**Industrial Perspective**

*Business Plan, Technological Needs*

Greatest need is for people who can steer and catch arrows!

Requires breadth, flexibility, persistence, teamwork, communication, discipline, …
Challenges for the Broader Physics Community

- Are industrial physicists valued by the community if they do not engage in “pure” physics research nor attend APS meetings?

- Will/can the mainstream culture adapt rapidly enough to the changing needs of industrial physicists and retain them as part of the community? How?

- Will the broader physics community also begin to experience creative destruction if industrial involvement declines?

FIAP welcomes your thoughts and suggestions!
Send to fiap-exec@aps.org