The Role & Adaptation of Physics as the Ideal Discipline for Innovation

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What is innovation?

Following Caesar: VC, VC, VC
  – Value conceived.
  – Value created.
  – Value conveyed.
Example: The Transistor

- **Conceived:** various methods to regulate electric charge motion in solids.
- **Created:** various stages of working transistor prototypes...including two different schemes (BJT and FET).
- **Conveyed:** technologies licensed to others, e.g. Texas Instruments & Sony, to make marketable products.
What is Entrepreneurship?

• An entrepreneur creates sustainable organizations and relationships to deliver value.

• This often requires a lot of time working with intangibles, particularly people’s motivations (herding Cheshire cats?).

• Sometimes entrepreneurship must augment physics knowledge even in order to achieve an important technical or scientific goal.
Physics students are ideal innovators because...

- They can approach design problems with a first-principles understanding.
- They can guide efforts through quantitative models and abstractions.
- They can recognize and apply physics as the foundation of a wide range of technologies.
- They are capable of systems thinking to understand how diverse components work together to make a functional product.
- They like challenges and aren’t afraid of risks.
Students in general are ideal innovators because...

• They bring unique life experiences and passions into the mix.

• They don’t know “what can’t be done” and are thus less inhibited from trying new approaches.

• They can benefit from working at the fuzzy boundary between creating knowledge and using knowledge.

• They can connect with peers from many disciplines and make the process fun.
Students are also advocates: NCIIA / University Innovation Fellows

At the June 5-6, 2014 meeting:

• Caleb Carr
  Premed / Biophysics Minor
  University of Colorado Denver

• Jaime Arribas Starkey
  Engineering Physics Major
  Morgan State University
If you are a student, why pursue innovation?

- The obvious: fame and $$$$$
- Skills for success: both technical and non-technical
- Feeding a passion or meeting a deep personal need
- Fun: you like solving hard problems.
- Satisfaction: you sleep better after helping people by creatively meeting their needs.
- Citizenship: society will support a discipline that creates value.
- Stimulation: real-world problems provide new research directions and metaphors for thinking.
- Independence: you can choose your own pursuit to the extent that you can find the time, physical resources and knowledge.
When to innovate?

• Innovate now, start businesses later.
  – Become an *Intrapreneur* in your research group or for an employer.
  – Mentor high school student innovators.
  – Watch for the right opportunity to take innovations to the next level (including starting a business).

• Create itches that have to be scratched.
  – Use current work as opportunities to exercises in innovation.
    (Example from my MIT days: a modular sensor power & signal conditioning system.)
  – Keep a “day book”, journal or other record of observed needs, opportunities, and ideas.

• Read up and talk to experts about the non-physics aspects of entrepreneurship.
If you are a physics department, why consider programs that foster innovation?

- To attract students who want to acquire work-related skills beyond physics that are crucial for career success.
- To have a wider impact of research helping with grant competitiveness, leading to tech transfer, etc.
- To link with industry to create ongoing collaborations and sources of employment for graduates.
- To engage with community to solve key problems.
- **SOCIETY NEEDS THIS!**
  - Physics is at the **nexus of most technologies** and can contribute strongly to the creation of **genuine value**.
Present conditions are excellent for physics student innovators...

- High tech devices are amazingly affordable
  - Arduino’s, Raspberry Pi’s, motor control units, communication devices, etc.

- Old “tech” equipment can be used for supplies
  - Dismantled for parts, e.g. stepper motors
  - Reverse-engineered, “hacked”, and re-purposed

- More sophisticated equipment is often donated or available as low cost surplus
  - From motorized wheelchairs to electron microscopes...
But some needs are harder to meet...

• Space. Space. Space.
• A **community** to share resources & ideas.
• Knowledge available “on demand” for a project.
• Practical experience.
• Gaining **innovation & entrepreneurship (I&E) skills** (needs finding, management, patents, finance, etc.)
• Finding a “fit” in the curriculum: credit or certification.
• **Professional recognition** for supporting faculty and staff.
Caution! Don’t underestimate the role of practical knowledge & experience.

- Physics fundamentals & “I&E skills” = 0

- Physics fundamentals & practical knowledge & experience & “I&E skills” = ∞
Where & how can you develop a photocopier? ... a product with lots of physics-based technology.
Battelle Memorial Institute

where Chester Carlson’s kitchen-table prototype was advanced to a viable product.
Where & how can you build a Mars Rover?
...amongst the best that our civilization produces.
JPL - a 5000 employee NASA lab (and universities & corporations)
What if we capture 52 core elements of the technical know-how of places like Battelle or JPL and bring this knowledge to communities?
Gateway High School
Aurora Public Schools, Colorado

Innovation Hyperlab
Introducing the Innovation Hyperlab

An extremely versatile physical & curriculum framework for fostering innovation from grade school to grad school.

... a collaboration with Aurora Public Schools bringing together K-12 and university students & faculty.
The motto...

Omnis Technologia Omnibus
(All of Technology for Everyone)
An Earlier Version: the Community Prototyping Lab

• Partnered with a nonprofit (Micro Business Development) that supported small businesses.
• Engaged undergrads to help clients develop early prototypes.
• We hope to bring this aspect back into the Innovation Hyperlab in coming years.
• Other places exist:
  – Club Workshop
  – Maker Spaces, including some in libraries
The 52 Technologies
Foundations

• Starting essentials
  01 Safety and hazardous materials
  02 Early prototyping
  03 Common tools
General technical resources

- Materials and manufacturing
  04 Materials
  05 Traditional manufacturing
  06 Advanced manufacturing
- Structures and infrastructure
  07 Structural systems
  08 Rigging and materials handling
  09 Buildings and infrastructure
- Energy and measurement
  10 Energy systems
  11 Measurement and standards
  12 Sensors
Mechanics

• Mechanical systems
  13 Mechanisms
  14 Actuators
  15 Vehicles

• Mechanical dynamics
  16 Rotating systems
  17 Vibration and chaos
  18 Sound and ultrasound

• Thermal and fluid systems
  19 Fluid systems
  20 Thermal systems
  21 Vacuum and high pressure
Electronics

- Analog electronics
  - 22 Electronic components and measurements
  - 23 Analog signals
  - 24 Active devices
- Digital technology
  - 25 Digital electronics
  - 26 Microcontrollers
  - 27 Human interfaces
- Radio frequency systems
  - 28 Radio-frequency electronics
  - 29 Remote control and telemetry
  - 30 Microwave systems
Computers, control, and advanced instrumentation

- **Computer technology**
  - 31 Computers
  - 32 Data storage
  - 33 Networks and data communication

- **Control and automation**
  - 34 Control systems
  - 35 Automation
  - 36 Robotics

- **Advanced instrumentation**
  - 37 Digital signal processing
  - 38 Advanced detection and measurement
  - 39 High-throughput data acquisition
Optics, fields, and particles

- **Optics**
  - 40 Optical systems
  - 41 Optoelectronics and lasers
  - 42 Imaging
- **Fields and particles**
  - 43 Magnetic fields and superconductors
  - 44 Electric fields and plasmas
  - 45 Particle beams and detectors
- **Nuclear technology**
  - 46 Nuclear instrumentation (alternate: Health physics)
Micro- and nanotechnology

• Microtechnology
  47 Microscopy and micromanipulation
  48 Microfabrication and thin films
  49 Microdevices and lab-on-a-chip

• Nanotechnology
  50 Nanoparticles and nanodevices
  51 Nanoscale measurement
  52 Scanned probe microscopy
Innovation Combinatorics

• Almost any device or process requires numerous technologies.
• Innovation Poker
  – Take any 5 technologies out of 52
  – 2,598,960 possible combinations
• Innovation Decathlon
  – Take any 10 technologies out of 52
  – 15,820,024,220 possible combinations
Lab Design Elements

• Clusters of 3 technologies shaped into bays formed by 3 x 1.5 x 6 ft shelves
• Combination of supplies & instructional equipment with next-to-most-recent research-grade instruments
• A work table in each bay
• Carts to transport projects between bays
• Work-in-Progress posters explaining ongoing projects
• Binders with relevant review articles plus trade journals
• Touch-screen monitors to deliver instruction (including video) and web access at each bay.
• Project storage lockers
Order versus Constructive Chaos

• We try to make parts and instruments **plainly visible** to stimulate imagination

• However, **we use stackable boxes and parts cabinets to make a more visually ordered space**

Thomas Edison: 
“**To invent, you need a good imagination and a pile of junk.**”
More Lab Design Elements

• Infrastructure drop-downs to each bay
  – Internet (wired and wireless)
  – 6 outlets (120V, 15A) of electric power (coming)
  – (Wish list item) Low voltage power

• Opportunistic use of special furniture
  – Library catalog cabinets
  – Computer punch card cabinets
  – Library microfiche / film cassette cabinets
  – (Wish list) Map/art and Chinese apothecary cabinets

• Additional storage
  – Tall “big-box store” shelving in the lab
  – 40 foot shipping container outside the lab
  – Off-site storage
Signage & Labeling

• “Street signs” named for contributors to science & technology from many cultures
• Overhead signs for each technology
• Labels with QR codes to link to online information & tutorials

The signage by itself is a major learning resource & creates a strong impression.
The lab is an equipment re-purposing “factory”

- Rapid assimilation of donated equipment & supplies
  - A place for everything
  - Labeled stock
- Incoming triage
  - Use as is
  - Repair
  - Dismantle for parts
  - Dispose
So we **have the resources**...

What can we **build** besides photocopiers or Mars rovers?
Rescue Helicopter Hoist Stabilization
Music-Scripted Actuator Motions in Biomechatronics
A smart bed to monitor persons at risk or undergoing extended care.
A vibrating platform to separate glass from imported food materials.
Quantum Effects in Cell Membrane Ion Channels
Powering Medical Devices Using Body Energy
The **Virtual Side** of the Lab

Website under construction:
https://sites.google.com/site/inventorsyeara/home

Intended for open release in July 2015.
Until then send request for access with a gmail address to:
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Each technical resource has knowledge elements to support a variety of ways to learn about each topic.

- .01 Quick engagements
- .02 Safety
- .03 Essential ideas
- .04 Technical repertoire
- .05 Equipment and supplies
- .06 Methods and special tools
- .07 Applications
- .08 Sneaky issues
- .09 Deeper analysis
- .10 Computer resources
- .11 Useful data
- .12 References and web sites
The knowledge building blocks can be assembled into various types of curricula

• **TechION’s**: a quick introduction to 3 ideas, 3 objects, 3 numbers + career examples.

• **Technical competencies**: a series of 3 to 5-hour units leading to certification in a technology

• **Application scenarios**: Case Studies
  – General context (e.g. designing a small-scale water treatment system)
  – Case study examples (how specific technologies are applied)

• **Professional training**: advanced versions of the technical competencies for teachers and industry personnel
Instructional blocks can be expanded to create formal curricula for both K-12 and colleges.

• **Innovation-focused physics curriculum** (possibly for college credit)
• **A new medical instrumentation sequence**
• Support for courses that require high school senior capstone experiences
• **Other courses (STEM and beyond) to evolve as the lab becomes operational**
• Mentoring opportunities for college undergraduates to work with K-12 – a means to attract future teachers!
Instructional Support

• Learning resources are compiled into exportable 17-liter plastic bins.

• Online curriculum plans can be custom-configured out of TechION’s, technical competencies, case study examples, etc.

• An inventory of video-based demonstration of technical procedures is in preparation.

• The Innovation Hyperlab can be extended via
  – Mobile labs (trailers, pods, etc.);
  – Partner “special-purpose” labs at other sites;
  – Others using the lab as an “IKEA style” source of modules.
And more at the university level

• On-demand courses on technology both at the early undergraduate and at graduate levels, leading to certificates.

• A hoped-for space similar to the Innovation Hyperlab that captures advanced instrumentation into a “commons”.

• Mechanisms to aid students, postdocs, and faculty launch start-up ventures.
Further support of innovation projects.

• **Web-based project management**
  – Needs analysis
  – Knowledge framework
  – Planning
  – Execution

• **“Quantum Publishing” of student work**
  – “Signifons” that archive student contributions in small pieces
  – Eventual accumulation into regular publications

• **Venture creation**
  – Business plan development
  – Management instruction
  – Collaboration with colleagues running a new microfinance group
University faculty, administrators & funding agencies take note!

• The Innovation Hyperlab can provide experience in research & innovation to 10x the number of students placed in individual labs.

• Cleverly used, the Innovation Hyperlab offers faculty a means to seed new directions in their own research.

• The Innovation Hyperlab can greatly expand the research resources for small departments.

• The Innovation Hyperlab can be a community innovation resource mediated by students.
Conclusion

Physics is a **superb discipline** to **foster innovation**.

Providing **space, technical resources, and on-demand learning** enables **students, teachers, and working scientists & engineers** to collaborate on innovation that society greatly needs.

The models can be easily replicated and improved. Please join us!
Collaborators

• Aurora career pathway directors: Carol McBride, Michael Bautista & Lynn Fair (and the district leadership under Superintendents Munn & Barry)
• Gateway High School principal: Bill Hedges (and his staff)
• Innovation Academy Director: Judy Bleakely
• Lab manager: Ron Vasquez and (in memoriam) Brad Busley
• Administrative coordinator: Jackie Shaw
• Teacher scientists in residence: John Miller, Brooke Ravanelli, Dawn Skala, Alice Sampson, Pat Roberts, Alejandra Morales, Marilyn Achten
• Teacher curriculum designers: Philip Breiding, Chris Hunt, Cole Hardy
• TAQ TIQ’ al team: Rachel van Scoy, Andrea Cortez, Lesley Tyk
• Undergrad mentors: Chris Zamora, Kevon “Kaveman” Hayes, Sara Abdelrahman, Meseret Tesfamariam, Jamie Wadell, Caleb Carr, Ben Straub
• And all the student innovators!