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

Randall Tagg

Physics Department – University of Colorado Denver

randall.tagg@ucdenver.edu

# 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.

Images from Wikipedia

# 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?

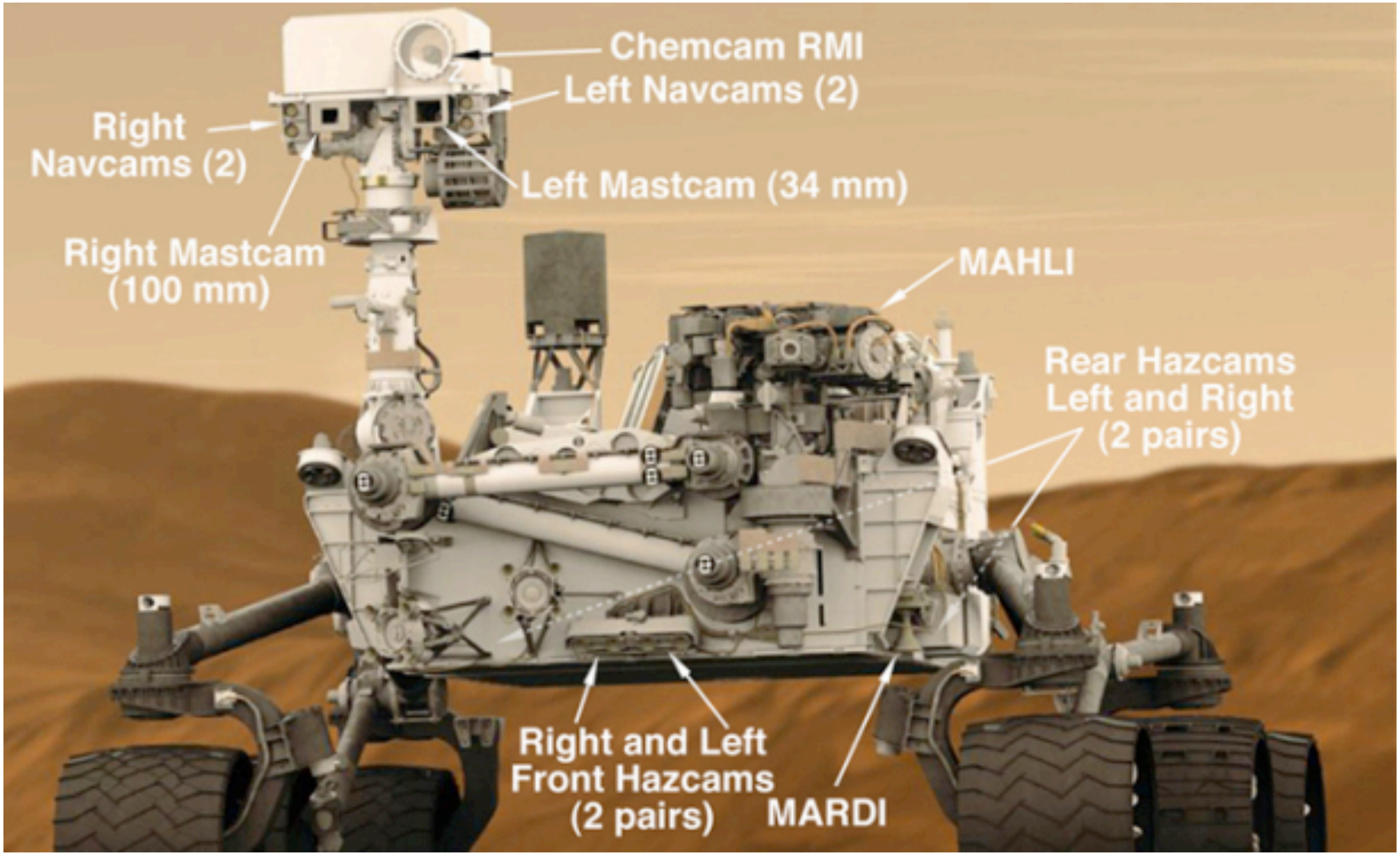
… a product with lots of physics-based technology.

# Battelle Memorial Institute

where Chester Carlson's kitchen-table prototype was advanced to a viable product.

# Where & how can you build a Mars Rover?

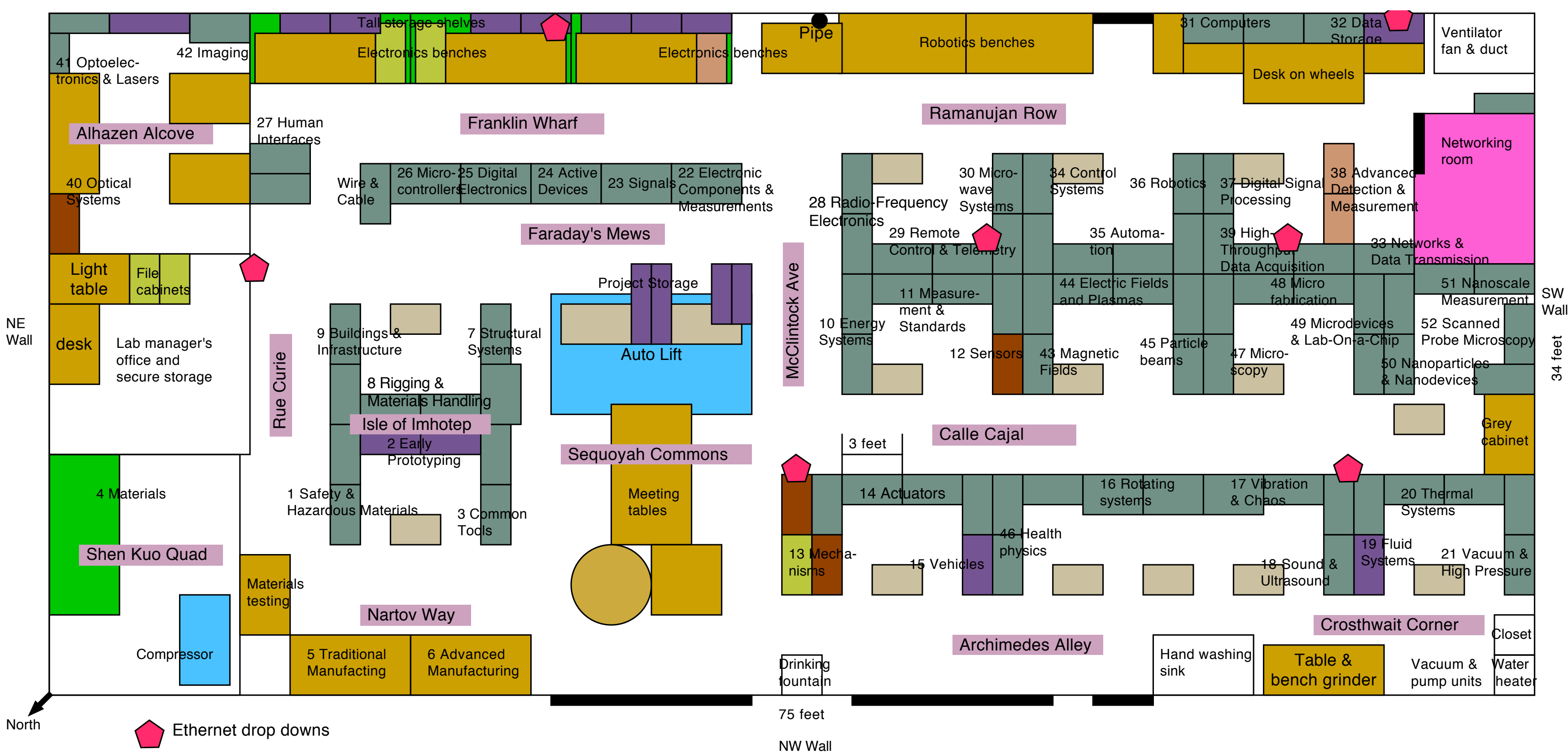
...amongst the best that our civilization produces.



# 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

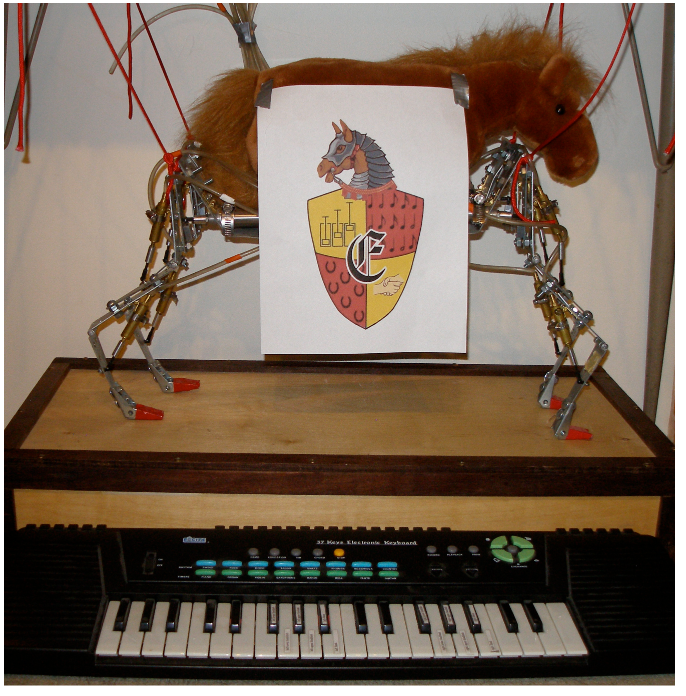
An extremely versatile
physical & curriculum framework
for fostering innovation
from grade school to grad school.

… 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

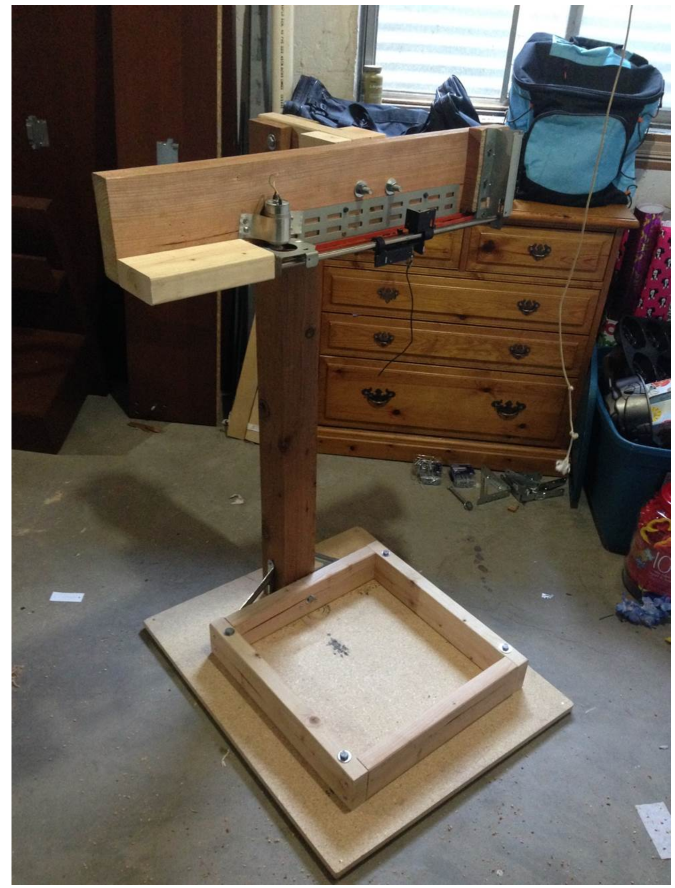

The signage by itself is a major learning resource & creates a strong impression.

# 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

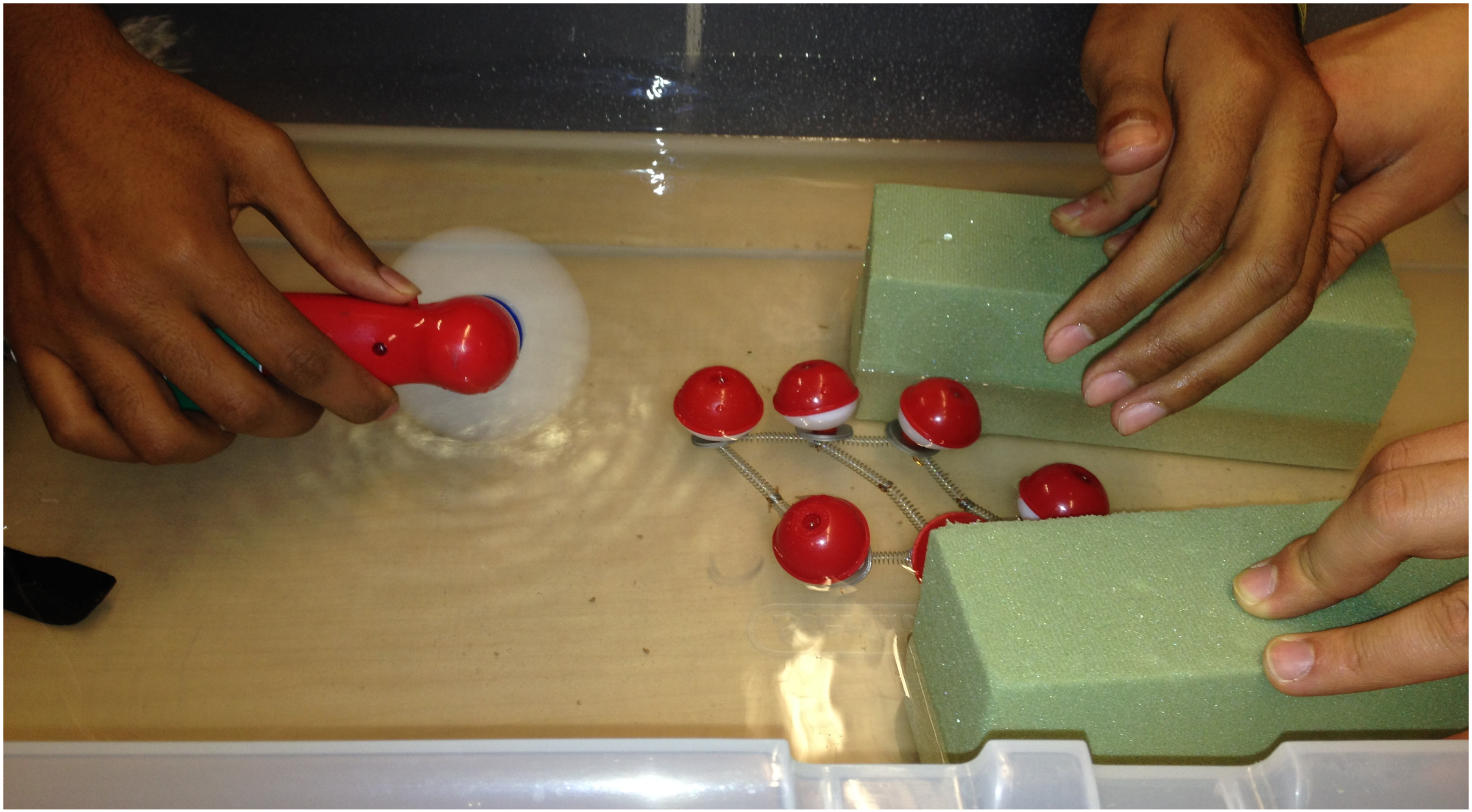


# Music-Scripted Actuator Motions in Biomechatronics

# 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:
randall.tagg@ucdenver.edu

# 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!