Technical Competencies Task Force Report **AAPT Committee on Laboratories**

Randall Tagg Physics Department, University of Colorado Denver 6 July 2021

Contents

1. Technical competencies task force and activities to date

a. Task force members

Randy Tagg – Univ. Colorado Denver – convener

Eric Ayars – Cal State Univ. Chico
Eric Black – Caltech
Sara Callori – Cal State Univ. San Bernadino
Bruno deHarak – Illinois Wesleyan
Yongkang Le – Fudan University, China
Kenn Lonnquist – Colorado State Univ.
Randy Peterson – University of the South
Sean Robinson – MIT
Kevin Van de Bogart – Univ. Chicago
Kasey Wagoner – Princeton

Also advising:
Forest Bradbury – Amsterdam Univ. – convener of the Makerlabs Discussion Group in Europe and USA
Karl Trappe – Austin Community College – developer of resources for the Physics Instructional Resource Association (PIRA)

b. Task force goals

The focus of this project is the part of the Lab Guidelines that refers to "developing technical and practical skills."
https://www.aapt.org/Resources/upload/LabGuidlinesDocument_EBendorsed_nov10.pdf
The goals are to
(1) Propose a classification scheme of technical competencies, perhaps hi-lighting some of the most desired competencies;
(2) Develop guidelines for modular and shareable learning materials for students and instructors to use in a variety of learning situations, ranging from independent learning to formal labs.
(3) Suggest criteria and methods for assessment that could lead to recognized certification in specific technical competencies.

c. Activities to date

- Initial formation: AAPT Summer Meeting, Provo Utah, Summer 2019
- Fall 2019: email exchanges with task force to identify "top ten" (or more) desired competencies for most majors and another five (or more) specialized competencies.
- Individual interviews with task force members at AAPT Winter Meeting 2020: Randy Peterson, Sean Robinson, Bruno DeHarak (Also: later zoom discussions with Gabe Spalding and Duncan Carlsmith.)
- Panel session BH01 – AAPT Winter Meeting 2020
    - Randy Tagg: "Identifying Technical Competencies Desired for Physics Majors - A Progress Report"

- Sean Robinson & Kristoph Paus: "Introductory Undergraduate Course on Experimental Physics Apparatus and Techniques"
- Bruno deHarak: "Technical and Non-Technical Competencies in an Engineering Design Course"

- Informal discussions and lab tours at CU Denver with visitors who had arrived early for the APS March Meeting 2020 – just before it was cancelled
  - Patricia Allen (Appalachian State Univ.)
  - Daniel Borrero (Willamette Univ.)
  - Joe Kozminski (Lewis Univ.)
  - Doug Petkie (Worcester Polytech)
  - Jonathan & Barbara Reichert & David van Baak (who had come in the TeachSpin Food Truck for the Mind!)
- Workshop W12 – "Technical Competencies in Laboratory Courses" – AAPT Summer Meeting 2020 (virtual)
  - Participants included: Glenda Denicolo (SUNY Suffolk), Farouzan Faridian (Santa Monica College), Evan Halstead (Skidmore), Tracy Hodge (Berea), Randy Peterson (Univ. of the South), Ronnie Spitzer (Berkeley), Karl Trappe (Austin Community College), Karen Williams (East Central Univ. Oklahoma)
- Attended several Discord / Zoom meetings of the MakerLabs group of roughly a dozen faculty in the Netherlands and the USA that was convened by Forrest Bradbury
  - This group was focused on adaptations to teaching remotely during COVID19 using resources such as Arduinos, sensor kits, and other items. There was a good overlap with more general ideas about student learning of technical skills.
- Attended session A2.3 Undergraduate Physics Education in China
  - Wonderful discussions with Yongkang Le and colleagues at several universities in China
- AAPT virtual coffee hour discussion of advanced labs and scientific apparatus – Feb 2,2021
  https://www.youtube.com/watch?v=DU1z3PZByfY
  - Thanks to Toni Sauncy, Gabe Spalding, and Mark Hannum. There about 20 participants. This was in part intended to discuss a possible ALPhA Mardis Gras event in the future to celebrate our favorite apparatus.
- Presented SPS Virtual Colloquium on May 12 on "physics for humans" at the invitation of Brad Conrad and facilitated by Michela Cleaver at SPS
  https://www.youtube.com/watch?v=17xrJG4Y2mI
  - This connects with the technical competencies work because it establishes the wider context for why students would want to acquire such knowledge and skills.

d. Forthcoming talks

vBFY 2021 Virtual "Beyond the First Year" Lab Conference – July 29
https://advlab.org/vBFY/
Helping Students Build a Repertoire of Technical Competencies for Physics Careers
Randall Tagg – Univ. of Colorado Denver

Successful application of the rich conceptual base of physics to research and to real-world problems requires a variety of technical, computational, analytical, statistical, and workflow competencies. Focusing on technical competencies, these will be defined as knowledge and skills related to the design and use of instruments, apparatus, devices, and physical processes. Common examples include building signal-conditioning circuits and assembling optical systems. Specialized examples include using drones for gathering geophysical data or preparing living samples for biophysical studies. It should be possible to create an inventory of practical learning modules that can be flexibly adapted to various needs as students participate in research, pursue internships, explore specific technical careers, and improve human lives. A structured approach to developing this inventory will be presented along with specific examples of laboratory experiences that help students build and document a personal repertoire of technical competencies.

(I also expect to run an afternoon workshop at vBFY on Self-sustained Oscillators as an example of an advanced technical competency).

SPS Invited Talk – AAPT Summer Meeting 2021 – Saturday August 31 1:30 at beginning of SPS Poster Session

The Compleat Physicist" – A Learning Framework for Human Impact

Randall Tagg - Department of Physics, University of Colorado Denver

Physics has proven itself capable of profound impact on human well-being. How might student physicists structure their learning to maximize their capacity to enjoy an intellectually stimulating career while actively solving important human problems? The "Compleat Physicist Model" suggests three major domains of learning. First is the foundational domain that is the core of our existing curriculum: analytical, computational and laboratory learning aggregate to create this foundation. This domain should be increasingly mirrored by student experiential learning in an applied domain where major areas of human activities are identified and the potential for physics-based contributions explored. Connecting foundations to applications is the competency domain in which an individual repertoire of practical skills is forged for translating physics into working technologies. The goal is to unify these domains so that students emerge with strong interest and sense of efficacy in improving the world in which they live.

e. Re-Launching the Task Force activities

I had planned to re-launch email exchanges with the task force after the 2020 APS March Meeting, where I was going to give a talk about this work at the Reichert Award Symposium. However, with the onset of the COVID-19 pandemic and remote learning, it seemed best to put active exchanges on hold while people dealt with the exigencies with colleagues and students at their campuses.

In place of this – and as a "silver lining" of having to shift to remote learning on our campus in Denver – the remainder of this report will consist of prototypes of materials that were developed for our own implementation of labs that deal with technical competency learning.

With this material serving as examples, I propose to re-launch active exchanges of the task force via a Zoom meeting early in the month of August after the AAPT summer meeting.

(Back to top)

2. Definition and purpose of technical competencies

a. Basic definition

Technical competencies are knowledge and skills that enable a person to design and use instruments, apparatus, devices, and physical processes.

Types of technical competencies include:

- design (e.g., circuit design)
- procedure (e.g., soldering)
- instrumentation (e.g., using a lock-in amplifier)

Other competency domains:

- analytical / mathematical methods (e.g., orthogonal expansions, complex functions)
- statistical / data analysis (e.g., linear and nonlinear regression)
- computational (e.g., ODE solvers, Fast Fourier transforms)
- workflow and workflow tools (e.g., working with bound and/or electronic lab notebooks, preparing presentations)

b. Purpose:

A person acquires technical and other competencies in order to fulfill objectives in carrying out scientific research and technical innovation and generally in translating fundamental knowledge into practical solutions to problems important to human and societal well-being. Building a repertoire of various domains of competencies is a key component in establishing credentials needed by a person to pursue a career that makes good use of knowledge of physics as a discipline.

c. Larger context:

In the following graphic display of topics under the title *The Compleat Physicist*[*], technical and other competencies occupy a middle ground between fundamental knowledge and human applications. The competencies enable translation from the deep synthesis of formal physics training into solutions of complex open-ended problems in real-world situations.
(See next page.)

(Back to top)

[*] This is a reference to the book "The Compleat Angler" published by Izaak Walton in 1653, thirty-four years before the publication of Isaac Newton's *Principia* in 1687.

PSI*
Physics Student Innovators
(*and alumni)

Knowledge Domains for the *Compleat Physicist*

Randall Tagg
Latest revision 11 Jun 2021
randall.tagg@ucdenver.edu

https://sites.google.com/site/psistarorg

Foundational Disciplines

Physics Subdisciplines

01 Mechanics & Nonlinear Dynamics
02 Electromagnetism
03 Thermal & Statistical Physics
04 Fundamental Quantum Phenomena

----

05 Nuclear & Elementary Particle Physics
06 Atomic & Molecular Physics
07 Optics & Photonics
08 Condensed Matter Physics
09 Fluid Dynamics
10 Acoustics & Ultrasonics
11 Plasma Physics
12 Astronomy, Astrophysics, Cosmology & Gravitation

----

13 Biophysics & Medical Physics
14 Chemical Physics & Physical Chemistry
15 Polymer & Soft Matter Physics
16 Mesoscopic Physics & Nanoscience
17 Complex Systems & Networks
18 Physics and Information
19 Geophysics, Atmospheric Physics & Ocean Physics
20 Environmental Physics
21 Physics in Archeology & Anthropology
22 Sociophysics & Econophysics
23 Art & Physics
24 Physics Education Research

Math & the Other Sciences

Mathematics
Chemistry
Biology
Earth Sciences
Environmental Science
Geography

Engineering

Mechanical Engineering
Electrical Engineering
Computer Engineering
Civil Engineering
Industrial Engineering
Architectural Engineering
Chemical Engineering
Bioengineering
Automotive Engineering
Aerospace Engineering
Naval Engineering
Ocean Engineering
Geotechnical Engineering
Environmental Engineering

Art, Humanities, Psychology & Social Sciences

Writing & Rhetoric
Languages & Cultures
Classics
Philosophy & Religious Studies
Value & Aesthetics
Ethics

Poetry
Literature
Creative Writing
Visual Art &Photography
Architecture & Design
Sculpture
Crafts
Music
Dance
Theater & Film

History
Anthropology & Archeology
Ethnic & Gender Studies
Psychology
Sociology
Political Science
Economics

Education and Human Development

(many fields corresponding to topics of learning and stages of development)

Methods & Technologies

Technical Repertoire

01 Design & early prototyping
02 Safety & hazardous materials
03 Hand tools & handheld power tools

----

04 Materials
05 Fabrication
06 Chemical methods

07 Energy systems
08 Measurement & sensors
09 Spectroscopic & analytical instrumentation

10 Structural systems
11 Buildings, labs & work areas
12 Geotechnics, hydraulics & land engineering

------

13 Machines & mechanisms
14 Actuators
15 Vehicles

16 Rigging & materials handling
17 Rotating, vibrating & chaotic systems
18 Sound & ultrasound

19 Fluid systems
20 Thermal systems
21 Vacuum & high pressure

------

22 Electronic test & measurement
23 Analog electronics & electronics construction
24 Radio frequency & microwave systems

25 Digital logic, FPGAs, microprocessors & microcontrollers
26 Computer-integrated data acquisition and control

27 Human interfaces
28 Control systems

29 Mechatronics, robotics & automation

-----

30 Computers, clusters & servers
31 Memory, data storage and input-output
32 High data throughput, neural networks, and artificial intelligence

33 Signal processing
34 Networks & communication systems
35 Geospatial systems & internet of things

-----

36 Optics & optical systems
37 Lasers & photonics
38 Imaging & remote sensing

39 Electric fields & plasmas
40 Magnetic fields & superconductors
41 Charged particle optics & instruments
42 Nuclear & elementary particle methods

-----

43 Microscopy & micromanipulation
44 Thin films, microfabrication & microdevices
45 Nanoscale microscopy & measurement
46 Nanotechnology & atom manipulation

-----

47 Molecular biology methods
48 Cell & microbiology methods
49 Plant & animal biology methods
50 Biomedical devices, instrumentation & imaging

----

51 Field work & outdoor skills
52 Extreme environments & space systems

Analytical Repertoire

Coordinate systems & trigonometry
Vector analysis
Tensors
Linear algebra
Group theory
Complex variables & analysis
Ordinary differential equations
Special functions

Integral transforms
Fourier analysis
Orthogonal function expansions
Partial differential equations
Integral equations
Calculus of variations
Differential geometry
Topology

Statistical Repertoire

Discrete probability & combinatorics
Probability distributions
Regression analysis

Stochastic processes
Stochastic differential equations
Game theory, agents, annealing, & evolutionary methods

Computational Repertoire

Computational Environments

Mathematica
Matlab / Simulink
CAD including stress computation
Comsol Multiphysics

Numerical Methods

Root finding
Linear algebra
  Matrix inversion
  Eigenvalues
Optimization
Integration
Ordinary Differential Equations
Partial Differential Equations
  Finite Difference
  Finite Element
  Spectral
Stochastic Methods
Image processing

Operating systems

Linux / Android / MacOS / IOS
Windows

Code & Website Development

Version control
  Github
Programming languages
  C/C++
  Python / Julia
  Java
R / IDL / SQL
  LabVIEW
Web Development
  HTML / CSS
  mySQL
  Javascript / PHP/Perl/Ruby
  Django /Rails
  Drupal / Joomla / Wordpress / Squarespace
Parallel computing CUDA
Mobile device development

Data Science

Machine learning & artificial intelligence
Data visualization
Data assimilation

Impact

Human Applications

01 Energy
02 Air & water
03 Food
04 Ecosystems, weather & environment

05 Dwellings & the built environment
06 Things for daily living
07 Maintenance, recycling & disposal
08 Transportation

09 Family, friends & community
10 Health
11 Education
12 Safety & security

13 Information & communication
14 Art, craft, hobbies & entertainment
15 Sports & recreation
16 Hospitality & personal services

17 Materials production
18 Manufacturing
19 Technical supplies, equipment & services

20 Marketing, distribution, sales & rental
21 Finance, insurance, & real estate
22 Management, legal services & government

23 Exploration
24 Future humans

∞ Creating knowledge

Workflow Repertoire

Managing Research & Innovation

01 Finding ideas, needs & opportunities
02 Preparatory learning
03 Project planning
04 Project management
05 Theoretical modeling
06 Code management
07 Apparatus / prototype design & construction
08 Protocol development & automation
09 Performing & documenting lab/shop/studio work & observations
10 Data management, analysis & display
11 Assessment and conclusions
12 Dissemination
13 Planning further iterations, pivots, spin-offs & new directions

Business & Entrepreneurship Repertoire

Need finding & customer discovery
Creativity and innovation
Intellectual property
Product definition and pricing
Market segments and revenue estimation
Business planning
Pitches & business communication
Teamwork & leadership
Work definition & management
Marketing
Creating & managing organizations
Human resources & supervision
Finance, accounting & insurance
Global partners & markets
Production planning & management
Supply chain management
Customer relations
Business law
Regulatory compliance
Business history & biography

Law and Civics Repertoire

(many fields that are aligned with the areas of human application and general aspects of citizenship & government)

3. Technical competency assays

A useful way to identify technical competencies is to enumerate the knowledge and skills needed to perform a project in research or technical development. We require such an assay of students when they create senior lab / independent research projects.

Here is an example from an original project initiated by a masters degree student on processing nanomaterials using a resonant microwave system. (This list was useful when hiring a student using funds from our campus undergraduate research office; the request for funding required a job description that identified skills that would be needed and/or learned.)

- Instruments:
    - Digital multimeter
    - Oscilloscope
    - Crystal detector
    - Vector network analyzer
    - Compact spectrometer (Ocean Optics)
    - Analytical balance
    - Sonicator
    - Centrifuge
- Design
    - Microwave resonator
    - Magnetron source incorporation
    - High voltage safety shield
    - Arduino-controlled power supply relay for microwave modulation
    - Waveguides
    - Microwave resonator
    - Field probe
    - Fiber optic spectrometer setup
    - Spectrometer cuvette holder with fiber optic ports
- Procedures
    - Machining of resonator
    - 3D printing of cuvette holder
    - Nanotube dispersion into surfactant solution
- Computation
    - FECO / MEEP / COMSOL field simulation
    - Temperature & concentration profiles

(Back to top)

4. Classifying and Listing Competencies

a. Hierarchical Technical Competency Classification Scheme

V5.0 Created 25 June 2019, last updated 05 July 2021

Levels in the hierarchy:

Repertoire – Area – Group – Topic (technical resource) – Subtopic

Code: T23o06Ds

Repertoire	T Technical (other choices are A Analytical C Computational W Workflow tools)
Area	23 Analog electronics and electronics construction
Group	o Op amp circuits
Topic (technical resource)	06 Basic amplifiers
Subtopic(s)	.01 Voltage follower – signal buffer .02 Inverting amplifier .03 Noninverting amplifier
Competency type	D Design (i**N**strumentation **P**rocedural) Design Subtypes: - **s** underlying science & design principles - **m** analytical & computational modeling **- d** design drawing &specifications - **b** build - **t** test & troubleshoot (If subtypes are not specified, then all are assumed to be included)
Specific focus	Applied to audio signals *(this and the next row permit context specific implementation)*
Conceptual framework	Amplifier is evaluated in terms of op amp golden rules but non-ideal characteristics are introduced e.g. limited gain-bandwidth product
Level	Aware, Ready, Capable, Proficient, Expert

The rows on “specific focus” and “conceptual framework” allow customization within a specific set of learning materials.

The row on “level” will be discussed further below.

For comparison see the PIRA Demonstration Classification Scheme
https://physicslearning.colorado.edu/Bib/PIRA%20DCS.htm

1	Area	(mechanics)
D	Topic	(motion in two dimensions)
60	Concept	(projectile motion)
.10	Demonstration	(howitzer and tunnel)

b. Classification Areas

Multiple possible ways of defining areas, groups & topics are possible, as became clear through discussions with members of the task force. We might call the following the **Denver-52 system**, since it was developed at CU-Denver and divides a wide range of technical knowledge intentionally into 52 areas. This system has utility through alignment with weeks in a year ("The Inventors Year") and with cards in a deck[*]. It was developed by consulting many systems of classification, including patents, products, industries, job types, etc. A provisional division into groups, topics, and subtopics is in another document.

01 Design & early prototyping
02 Safety & hazardous materials
03 Hand tools & handheld power tools
----
04 Materials
05 Fabrication
06 Chemical methods

07 Energy systems
08 Measurement & sensors
09 Spectroscopic & analytical instrumentation

10 Structural systems
11 Buildings, labs & work areas
12 Geotechnics, hydraulics & land engineering
------
13 Machines & mechanisms
14 Actuators
15 Vehicles

16 Rigging & materials handling
17 Rotating, vibrating & chaotic systems
18 Sound & ultrasound

19 Fluid systems
20 Thermal systems
21 Vacuum & high pressure
------
22 Electronic test & measurement
23 Analog electronics & electronics construction
24 Radio frequency & microwave systems

25 Digital logic, FPGAs, microprocessors & microcontrollers
26 Computer-integrated data acquisition and control

27 Human interfaces
28 Control systems
29 Mechatronics, robotics & automation
------
30 Computers, clusters & servers
31 Memory, data storage and input-output
32 High data throughput, neural networks, and artificial intelligence

33 Signal processing
34 Networks & communication systems
35 Geospatial systems & internet of things
------
36 Optics & optical systems
37 Lasers & photonics
38 Imaging & remote sensing

39 Electric fields & plasmas
40 Magnetic fields & superconductors
41 Charged particle optics & instruments
42 Nuclear & elementary particle methods
------
43 Microscopy & micromanipulation
44 Thin films, microfabrication & microdevices
45 Nanoscale microscopy & measurement
46 Nanotechnology & atom manipulation
------
47 Molecular biology methods
48 Cell & microbiology methods
49 Plant & animal biology methods
50 Biomedical devices, instrumentation & imaging
----
51 Field work & outdoor skills
52 Extreme environments & space systems
----
99 Other

[*] This deck of cards has been used in design workshops at Society of Physics Student events, including the 2016 and 2019 Physcon conferences.

c. Task force list of competencies – a first pass

Responses are grouped into the matching classification areas

00 Broad overviews of technical resources

01 Design and early prototyping

- How to make and read a drawing: basic paper drawing, CAD
- Extract device parameters from technical documents (e.g. manuals, datasheets, online listings)
- CAD drawings of experimental systems: vacuum systems, electronics, particle detector setups

02 Safety and hazardous materials

- Knowing under what circumstances to use protective clothing, closed toed shoes, thermal or electrical or wear & tear proof gloves, glasses for general safety or UV/chemical protection, respirators, hearing protection, removal of jewelry, etc...
- Fire safety
- Fire extinguishers
- Safety in handling high-temperature systems and materials
- Electrical safety
- Repairing damaged power supplies
- Safe practices while troubleshooting electronics
- Laser safety - using/providing eye protection, building enclosures for laser demonstrations, containing stray reflections
- Chemical safety
- Safe use of hand tools and machine tools
- Safe handling and storage of magnets
- EM field radiation exposure guidelines
- Cyrogenic/Liquid nitrogen safety
- Radioactive material handling and storage, acquiring and disposing of sources, how these topics vary for the different types of radiation

03 Hand tools and handheld power tools

- Proper use of wrenches, files
- How to safely use an electric hand drill

------

04 Materials

- Know the pros and cons of different raw materials: plastic, aluminum, steel (at a minimum)

05 Fabrication

- Measuring and scribing skills
- Basic metal fabrication skills
- How to tap a hole
- Drill press, milling machine, table saw, band saw, lathe, grinding/polishing wheel, disk/belt sander
- Lathe and mill operation
- Welding
- 3D printer
- Laser cutter
- Fastening and joining methods

06 Chemical methods

07 Energy systems

- Outlet sources
- Understand function of breaker boxes and circuit breakers
- Constant current / constant voltage power supplies
- Variable transformer

08 Measurement and sensors

Analog measurement tools: meter stick, calipers, micrometers
Measuring and scribing skills: avoiding parallax
Timing devices: stopwatch, photogates, other counters, etc.
Select an appropriate temperature measurement device for a given experiment (thermometer, infrared camera, thermocouple, solid-state, thermistor, etc.)
Select an appropriate light measurement device for a given experiment (such as a CCD, PMT, or photodiode)
Optical depth
Decibel
Solid angle
Hall effect magnetometer
Accelerometers

09 Spectroscopic and analytical instrumentation

Spectroscopic measurements
Design experiments to use resonance: resonant cavities (microwave and optical), electron-spin resonance, nuclear magnetic resonance, piezoelectric resonators, mechanical resonance

10 Structural systems

11 Buildings, labs, and work areas

Basic home-repair topics (electrical wiring, plumbing, welding, using a saws-all or rotary cutter, etc.)
Understand function of breaker boxes and circuit breakers

12 Geotechnics, hydraulics, and landscape engineering

------

13 Machines and mechanisms

Know about different types of screws
Know where to get hardware

14 Actuators

15 Vehicles

16 Rigging and materials handling

17 Rotating, vibrating, and chaotic systems

18 Sound and ultrasound

Decibel

19 Fluid systems

Know how to use compression fittings, NPT fittings
Know how to use a tube cutter

20 Thermal systems

Bunsen burners, torches
Liquid nitrogen storage, transfer, and use

21 Vacuum and high pressure

Compressed air or other gasses use
Vacuum technology: roughing pumps, turbo pumps, various types of gauges

------

22 Electronic test and measurement

Oscilloscopes: periodic, pulse, stochastic signals
Ammeter, voltmeter, digital multimeter
Four-point measurement
Function generator, constant current / constant voltage power supplies, digital multimeter, FFT network analyzer, lock-in amplifier
Using test & measurement instrumentation for troubleshooting
Self-testing of instruments: measure known signal on an oscilloscope to check connections, measure photodetector dark-count to check against specifications

23 Analog electronics and electronics construction

Passive components: resistors, capacitors, inductors
Wire sizes (smaller gauges mean bigger wire, bigger wires can carry more current, have a sense of how big various gauges are)
Transformers, variable transformers
Coax cables
Impedance matching

Circuit analysis: Ohm's Law, Kirkoff's laws
Voltage dividers
Passive filters: low-pass, high-pass, notch
RLC circuits

Semiconductors: diodes, transistors
Basic op-amp circuits
Feedback
Active filters: low-pass, high-pass, notch
Integrators and differentiators
Waveform filtering and conditioning
Voltage and current sources

Soldering, stripping wires, crimping wire connectors and terminal lugs, using wire nuts
Drawing and reading schematics, circuit diagrams
Generating a wiring diagram from a schematic
Constructing and testing a prototype using a prototyping board
Designing, ordering, stuffing, and testing a printed-circuit board

Do simple troubleshooting tests, e.g. jiggling wires
Use test and measurement instrumentation for troubleshooting
Make simple fixes/repairs to circuits
Read and use circuit technical manuals to help with troubleshooting
Observe safe practices when troubleshooting

24 Radio-frequency and microwave systems

Coax cables
Impedance matching
Wireless sensing and transmission

25 Digital logic, FPGAs, microprocessors, and microcontrollers

Basic digital circuit design
Using an FPGA as a pre-processor

26 Computer-aided data acquisition and control

Automate data entry/collection measurement via computer (e.g. recording data via microcontroller serial connection, using a commercial data logger, controlling position/frequency from software)
Using software to interface with instrumentation, e.g. LabVIEW
Computer-instrument interface via GPIB
Analog-to-digital converter

Motor control, position control

27 Human interfaces
28 Control systems
29 Mechatronics, robotics, and automation

------

30 Computers, clusters, and servers

Use of computers for (laboratory) data processing

31 Memory, data storage, and input-output
32 High data throughput, neural networks, and artificial intelligence
33 Signal processing

Models of device noise
Distributions for describing noisy systems: Gaussian, Lorentzian, etc.
Noise-reduction methods and instrumentation: using lock-in amplifiers and discriminators
Waveform filtering and conditioning
Interpret diffraction/scattering data and extract physical information from the patterns produced (ubiquitous form of indirect measurement)
Heterodyne and homodyne detection
Response function, also known as Green's function, point spread function, transfer function, gain function, impulse response, linear response, fundamental solution, and (sometimes) correlation function, depending on the context

34 Networks and communication systems
35 Geospatial systems and internet-of-things

------

36 Optics and optical systems

Basic optics course (e.g. using textbook by Hecht)
Interference filters
Diffraction gratings
Optical alignment methods
Optomechanics
Optical depth
Optical interferometers: Michelson, Mach-Zender, Fabry-Perot

37 Lasers and photonics

Lasers: diode, HeNe
Photodiode detectors

38 Imaging and remote sensing

Response function, also known as Green's function, point spread function, transfer function, gain function, impulse response, linear response, fundamental solution, and (sometimes) correlation function, depending on the context
Interpret diffraction/scattering data and extract physical information from the patterns produced (ubiquitous form of indirect measurement)

39 Electric fields and plasmas

Safely using high-voltage sources

40 Magnetic fields and superconductors

Magnet handling and storage
Helmholtz coils

41 Charged particle optics and instruments
  Magnetic trapping
42 Nuclear and elementary particle methods
  Radiation detection and measurement: Geiger counter, gas proportional counter, scintillator (NaI, plastic), PIN detector
  Radioactive check source
  Spectroscopy using pulse-height analysis
  Single channel analyzer
  Scalar/counter
  Using a multi-channel analyzer: pulse height and scaling modes
  Time-of-flight measurement
  Coincidence measurement
  Time-to-amplitude converter

------

43 Microscopy and micromanipulation
  Fluorescence microscopy
44 Thin films, microfabrication, and microdevices
45 Nanoscale microscopy and measurement
  X-ray diffraction
  Atomic force microscopy
  Scanning electron microscopy

46 Nanotechnology and atom manipulation

------

47 Molecular biology methods
48 Cell and microbiology methods
49 Plant and animal biology methods
50 Biomedical devices, instrumentation, and imaging

------

51 Field work and outdoor skills
52 Extreme environments and space

99 Other

NOTE: Many additional suggestions from the Task Force fall into the other competency repertoires (e.g., computational) and will be used to develop corresponding learning materials.

d. Provisional fine-scale list of areas, groups, topics, and subtopics

A first pass at identifying possible groups, topics, and subtopics is made. This list can and should be through several additional passes.

See document TechnicalRepertoire_AreasGroupsTopics_4.pdf

(Back to top)

5. Evaluation criteria

Points to consider in evaluating design, procedure, and instrumentation competencies. Not all points might be evaluated in a given instructional setting.

a. Design Competency – Proficiency Criteria

Capacity	Proficiency Criterion
Creating design goals within constraints	Able to quantitatively define two or more design goals and precisely enumerate two or more constraints that must be satisfied by a design.
Awareness of design options	Able to quickly list three or more choices for a central design component or subsystem that might provide the necessary capabilities.
Quantitative performance metrics	Able to know two or more performance metrics that determine the suitability of the design, including selected technical components, with a rough idea of the numerical values that ought to be achieved.
Creating and documenting a design	Able to integrate selected components into a design and to record the design using standard graphic representations.
Supporting a design rationale using fundamental principles	Able to cite two or more scientific principles underlying the behavior of the design or of its selected technical components, with an appreciation for how these historically drove the development of the associated technology.
Design modeling	Able to use one or more mathematical relationships governing the design's behavior to predict a measurable aspect of performance.
System integration	Able to model the interaction of the subsystem and its components with one or more other elements of a more complex technical system, suggesting strengths and weaknesses of the interaction from a system behavior standpoint.
Fabrication, installation and operation	Able to install the subsystem and its components into an actual physical realization, to operate the system once configured, and to refine the installation or operation as work proceeds.
Establishing test protocols	Able to set up a test protocol that is motivated by the application context, to enumerate acceptance criteria for meeting design goals, and to show robustness of performance under a range of operating conditions.
Design improvement	Able to identify means to quantitatively improve one or more performance metrics.

b. Procedural Competency - Proficiency Criteria

Capacity	Proficiency Criterion
Tools	Able to select and correctly use the right tools for the job, with an awareness of specialized variations and adaptations.
Setup and finishing	Able to prepare ahead of time, knowing what ancillary materials to bring to the work and what jigs and fixtures facilitate the process. Able to artfully apply finishing touches to the final product and leave a clean work area.
Manipulative skills	Able to coordinate movement and use touch and proprioception to safely and correctly handle tools and work pieces.
Visual & sensory frameworks	Able to use formal and mental visual models to guide the process and ensure correct outcomes. Other senses are also used, augmented when appropriate with instrumentation. Able to maintain a mindful and self-correcting oversight of the process, with attention to safety and integrity of the work.
Workflow	Through repetitive practice, able to maintain a steady process with routine aspects guided subconsciously.
Process model	Able to explain how procedures reflect fundamental principles, concepts, and quantitative relationships.
Quantitative performance metrics	Able to quantitatively describe process and product attributes. Able to measure outcomes against desired quality standards, using appropriate instruments and calibrations.
Adaptation and improvisation	Able to adapt to circumstances that might involve compromises in materials and tools and to alter processes to meet special needs and opportunities.
Documentation	Able to document key attributes of the process so that it can be replicated and / or altered, with clear identification of novel aspects and challenges.
Exploration and improvement	Able to use personal exploration, discussion with other practitioners, reading, and practice to hone skills, learn new techniques, and overcome process and material limitations.

c. Instrumentation Competency - Proficiency Criteria

Capacity	Proficiency Criterion
Use of main features	Able to adroitly use the main controls and interpret the displays and outputs to obtain the results for functions that are used 80% of the time.
Use of higher order features	Able to access higher-level features that provide deeper measurement and control function.
Probes, cables, and fixtures	Able to properly install, connect, and adapt standard probes, cables, and fixtures; able to understand limitations and precautions; able to customize these accessories to unique measurement tasks.
Programming and connectivity	Most instruments now have software control and methods of connection to host computers, portable devices, and the internet. Thus must be able to implement such software and connectivity using both industry standard and custom protocols and techniques.
Modeling instrument function	Able to describe the operating principles of the instrument, including block diagrams and quantitative models of sub-systems.
Performance metrics	Able to identify the quantities of accuracy, stability, and other attributes that define an instrument's quality, and can exercise good judgment in making price/performance tradeoffs in selecting instruments.
Limitations and appropriate use	Knowledge of where errors and interference can enter the instrumentation setup; awareness of physical and safety limits on instrument usage.
Effect of operating environment	Understanding of the effects of temperature, humidity, vibration, electromagnetic interference, etc. on the instrument's performance.
Maintenance and calibration	Able to implement troubleshooting protocols and use manufacturer’s literature to detect and fix problems.
Avenues for improvement	Able to identify ways to augment a given instrument and to state paths to the next level of performance if a measurement or control problem demands higher performance.

(Back to top)

6. Levels of knowledge and achievement

Here is a possible hierarchy of achievement, subject to further definition and refinement. (This has not yet been discussed by the task force.)

○ **Aware**

Outcome: By completing a learning module at this level, a student becomes aware of a type of technical resource in terms of what it can do, conceptually how it performs its function, examples of actual use, comparison to other resources that perform the same or similar functions, hands-on experience with one realization, and some quantitative description of performance.

Effort: 4 hours including one 2-hour lab session

Each session presents and stimulates excitement about the capabilities of a particular technical resource and its physical foundations. The resource (e.g., a mechanical gear drive train) is introduced within a broader perspective of similar resources (e.g., other types of drive trains) and then conceptual modeling and hands-on work create awareness of design possibilities that can be fulfilled with further learning.

Written material: 8 pages of supporting text, graphics, and computer code with clear connection to physics concepts

Format: 1/2 hour of video[†] or live presentation + ½ hour of associated reading and calculations + 2 hours of active lab work and data analysis + 1 hour of further analysis, calculations, reflections, and conclusions

● **Ready**

Outcome: By completing a module at this level, a student becomes ready to use a resource in actual practice through simplified physical modeling of relevant attributes and their interrelationships, experimental testing of an actual realization in comparison to the models, specification of key design components or operational parameters that must be chosen to adapt the resource to an application, and identification of performance measures that would define the resource's suitability to a given task.

Effort: 8 hours including two 2-hour lab sessions

This is a primer level of engagement, in which each technical resource is introduced in one session and further explored and quantitatively modeled in the second session. This is the desired approach for the introductory Applied Physics Lab for physics majors, perhaps also for a first course in Computational Methods. Students learn to quantitatively model and critically evaluate a technical resource, relating its function to underlying physics concepts and application contexts. By working with an actual example, students acquire a basis from which to begin to adapt the resource to new situations when the students join research groups, go into internships, or undertake independent projects. However, additional learning and experience will be needed to independently use and design with the resource.

Written material: 10 pages of supporting text, graphics, and computer code with clear connection to physics concepts

---

[†] Video material for all types of modules will typically be broken up into 6–10-minute segments.

Format per topic: 1 hour of video or live presentation + 1 hour associated reading and calculations + 4 hours of active lab work and data analysis + 2 hours further analysis, calculations, reflections, and conclusions. Weekly, this translates to ½ hour video, ½ hour preliminary reading, 2 hours of lab, and 1 hour follow up.

Capable

Outcome: By completing a module at this level, a student achieves independent functionality and design capability with a technical resource and/or group of similar resources. Physical modeling with mathematically sophisticated (calculus-level) relationships is used to predict and modify a resource's behavior. Several variations of the resource are explored through laboratory investigation, emphasizing a range of applications and assessing limits on performance. Some of the internal aspects of complex resources and design subtleties are revealed, opening a path to later detailed study. Experience is gained in troubleshooting and fault diagnosis. Later, further experience in the context of open-ended problems will develop deeper insight and confidence.

Effort: 20 hours including five 2-hour lab sessions

A full-semester 2-credit 2-session-per-week electronics course could be parsed into six competencies at this level with topics such as passive circuits, diode circuits, transistor circuits, op amp circuits, filters, and digital circuits. A comparable 2-credit practical optics course could be parsed into six competencies at this level, such as light sources, optical materials, basic lens & mirror elements, optical mounts, prisms & polarization optics, and multi-element optical systems. Another 2-credit course could offer more techniques in computational physics such as root finding, numerical integration, simulating ordinary differential equations, linear algebra, Fourier transforms, and use of special functions.

Written material: 40 pages of supporting text, graphics, and computer code with clear connection to physics concepts

Format per topic: 2 1/2 hours of video or live presentation + 10 hours of progressively open-ended laboratory work + 7 1/2 hours outside reading, calculations, data analysis, and writing conclusions. Weekly, for a 2-credit course, this translates to 1 hour of video + two 2-hour labs + 3 hours outside work for two and a half weeks per topic.

◆ Proficient

Outcome: By completing a module at this level, a student has demonstrated versatility and depth of insight in the use of a complex technical resource or resource group. The principal means of such demonstration include advanced modeling, testing to the limits of performance, systems integration with other resources, and application to an open-ended problem.

Effort: 60 hours including ten 2-hour lab sessions (see format below)

A student who is already familiar with a technical resource explores its internal design, operational subtleties, and variations in detail. In the lab, an important goal is to gain a higher level of versatility in using the technical resource or in adapting a procedure under varied circumstances. The student experiences the state of the art in realizations of the technical resource, or in some circumstances, creates a unique adaptation of more basic components to achieve a sophisticated level of performance The student develops an application to an open-ended problem – perhaps a problem drawn from the student's own work. Complex thinking, advanced mathematics, and numerical simulation is used for specification, design, and testing. Testing to failure or under unusual conditions provides deep appreciation of the resource's capabilities and limitations. Systems integration of the technical resource with other resources is required to meet the goals of an open-ended application.

In a full-semester 3-credit senior/graduate level course on “Scientific Instrumentation”, students might choose three advanced topics from a list and pursue them individually. Examples include electronic oscillators & signal sources, microwave cavities & measurements, semiconductor device characterization, and advanced optical spectroscopy techniques. The graduate-level version would require more extensive analysis and/or numerical modeling as well as documentation of a deeper level of integration into a specific application related to the student’s professional studies.

Written material: 120 pages of supporting text, graphics, and computer code with clear connection to physics concepts and complex applications. It likely this material would be part of a monograph or a section of an advanced “methods” book series. Students would be encouraged to read extra material as much as possible.

Format per topic: 10 hours of video or live presentation + 20 hours of progressively open-ended laboratory work + 30 hours outside reading, calculations, data analysis, and technical document preparation as well as possible additional lab time. In a one-credit 5-week module with one topic or a three-credit full-semester course with three topics, this would translate weekly to 2 hours of video / live presentation, two 2-hour lab sessions, and 6 hours of outside work / additional lab time.

Note that a larger fraction of time is applied to outside work with conceptual underpinnings, modeling, and analysis. Extra lab time might be needed to adapt the resource to a unique application. Content is largely harvested from active research settings.

◆◆ Expert

Registering under a directed-research course for 1 to 3 credits, a student or experienced practitioner will spend 4 to 12 hours per week (or more) advancing the state of the art with a particular technical resource or in achieving an innovative application of the resource to a research topic or to a real-world problem. The outcome could be a detailed technical report, a journal paper and/or an invention.

(Back to top)

7. Evidence of achievement

How shall students accumulate evidence of their knowledge and skills with technical topics?

Such evidence can serve as
- Direct material to show others, including peers, professors, and potential employers, what has been accomplished.
- A lifetime record for future reference and use professionally.
- A basis for formal certification.

a. Notebooks
Methods of recording include:
- Conventional laboratory notebooks
- Electronic notebooks that include data, graphics and images
- Executable notebooks like Jupyter notebooks (or Matlab and Mathematica variants) that also include formatted mathematics, reference to data files, graphics, and images … as well as executable code.

b. Physical artifacts
Tangible evidence includes actual constructed artefacts as well as photos and technical documentation of performance characteristics.

c. Portfolios and Github repositories

A comprehensive digital portfolio archive can be designed to archive the above items, render an attractive display of achievements, and disseminate materials.

Also, Github archives might be constructed for code and other digitally-formatted materials.

Connection to learning materials:

The next section on learning materials can and ought to be developed so as to naturally generate types of evidence listed above.

Future work for the task force:

Can we arrive at a uniform guideline and resource specification for the above types of evidence?

(Back to top)

8. Learning resources: instructional materials

a. Templates

One of the major goals of the task force is to develop some possible templates for learning materials for helping students learning technical competencies in various learning situations:

- Formal laboratory/classroom instruction augmented by written / video-based instruction.
- Guided independent learning on a "just-in-time" basis using university facilities, direct instruction, and written / video-based
- Document and video-based instruction for independent remote learning.

The following pages show one template that can serve all of the above modalities. It is actually configured as a Jupyter notebook. It is best suited to the Awareness / Ready / Capable levels of instruction and learning.

Templates for instruction at the proficient level are under development. This includes an example for deeper understanding of micro-controller mediated computer data acquisition and experiment control.

b. Inclusive design

Learning of technical competencies should be inclusive of people with varied abilities, including those who have impaired vision, loss of hearing, limited mobility, manipulative difficulty, or cognitive variation. This presents challenges as well as tremendous opportunities. The challenges arise because many technical competencies, such as operating instruments like oscilloscopes or performing procedures like soldering, strongly depend in their common manner of execution on sight, manipulative skills, etc. But important opportunities exist in creating new aspects of device, instrument, and process instruction that can enable learning for people with varied abilities and at the same time expand the insights and knowledge gained by all practitioners. An example might be the sonication of data that yields new ways of assimilation even for people with full visual capacity.

A forthcoming report from the Committee on Laboratories Task Force on Accessibility convened by Dimitri Dounas-Frazer will provide many useful guides for inclusive development of technical competency learning resources.

c. Repositories

Examples of instruction according to this template will be progressively uploaded to a Github repository during AY 2021-2022. The repository is under development and can be found at: https://github.com/InventorsYear

As new learning modules are added to this Github site, they will be listed by a designation Txx_yyy_Description, where xx is an area designator (00 to 52 or 99) and yyy is a progressive increased number (001 to 999). The documents common to a given area are stored in a special repositor beginning with Txx_000_. (Searching with the ext _000_ and sorting by name will list all of the major areas.)

d. Dissemination

The Github repository forms a base level means to store emerging instructional modules and other learning resources. The next step will be to create a website that will provide more friendly, hierarchical,, and cross-referenced access to the Github resources. The final stage will be to incorporate these materials into an AAPT / ALPhA sanctioned resource hub like COMPADRE and/or a Professional Competencies Portal designed along the lines of the Physics for the Life Sciences portal.

(Back to top)

Physics Enhanced Technical Ability Laboratory (PETAL)
(template)

Competency Area and Title, e.g.,T04 Tensile Testing of Wires

(Include an image of the experiment here.)

Jump to the experimental section.

1 Classification

Code: T04k01DsmdtN

Repertoire	T Technical (other choices are A Analytical C Computational W Workflow tools)
Area	04 Materials
Group	k Materials mechanical properties and continuum mechanics
Topic (technical resource)	01 Tensile testing
Subtopic(s)	.01 Metal wires .02 Polymer filaments
Competency type	D Design (i**N**strumentation **P**rocedural) Design Subtypes: - **s** underlying science & design principles - **m** analytical & computational modeling **- d** design drawing &specifications - **b** build - **t** test & troubleshoot (If subtypes are not specified, then all are assumed to be included)
Specific focus	Obtain Young's modulus and yield strength by measuring force versus length of a wire pulled using a hand-operated lead screw
Conceptual framework	Metal wire responds to extensional force by elastic and plastic deformation followed by fracture
Level	Aware, Ready, Capable, Proficient, Expert

NOTE: Design Competency subtypes may be specified, so for example the "s" in T04k01DsmdtP indicates that the underlying **s**cience of **D**esigning with materials is included as part of the learning. The choices for design subtypes are:
- s underlying science & design principles
- m analytical & computational models
- d design drawing & specifications
- b build
- t test & troubleshoot

If no subtype is specified, then all are assumed to be included in the instruction.

A learning module will likely include other competencies

Ancillary topics: S03a01 T26d02

Repertoire	Topic (technical resource)
Computational	Numerical method for linear least squares fit to data
Technical	Using a ARM Cortex M4 microcontroller for computer-based data acquisition and control

2 Why this is useful

This section describes how the knowledge and skills gained are useful in performing scientific research and in creating solutions to problems in various areas of human application. Some brief examples might be provided.

3 Learning goals

The material that should be worked through and the deliverables to be provided are outlined. These may be assigned to different levels of achievement:

- Aware: evidence is provided on achieving perspective (section 4) and using a pre-built version of a device or doing a simple instance of a procedure (a first-level version of section 8).
- Ready:
- Capable:

Two higher levels *Proficient* and *Expert* require different and more extensive content and actions. **Section 10 Further Exploration** provides a doorway to work towards these higher levels.

4 Perspective, preparatory readings, and websites

A description is given for how the primary topic fits into the area from which it is drawn. Other choices for how the technology or method might be achieved are enumerated so that a person becomes aware of options to consider.

Then links to websites and a guide other sources of reading materials (including items listed in the bibliograph section 12) are identified for wider initial exploration of the topic and its background.

5 Underlying ideas and connections to physics

This is the key section for identifying underlying ideas and connecting the technical topic to physics. How do physics concepts provide insight into why a device or process works the way it does? How does such insight suggest variations, enhancements, and connections to other practical issues.

This section consists of

- Text
- Equations

- Video
- Numerical simulations and graphics that help explore the quantitative nature of the physical concepts
- Exercises
- Written reflections

This section might largely be set up for self-study and self-paced inquiry, with guiding questions to direct the process along with some suggested readings from physics texts.

The material can be divided into two levels of learning, serving students at different stages of learning about physics.

Essential ideas

Uses algebra, trigonometry, and basic functions like exponential and logarithm.

More advanced concepts

Uses complex numbers, calculus, vectors, vector analysis... as well as physical models from 2nd and 3rd year college physics courses, etc.

6 Technical description and modeling

This is where a detailed presentation of the specific focus idea is created, building from the underlying physics concepts. A goal is to create both descriptive and quantitative models, including mathematical analysis and computer simulation. Python code cells are often an important part of this section.

A key function of this section is to lay the groundwork for both the laboratory processes and the subsequent data analysis and reflections.

In a formal course, this section might be done "live" in class so that there can be active discussion. Some aspects of this can be staged for student teams to first explore amongst themselves.

Additional exercises might be included in this section.

Basic models

More advanced models

7 Equipment and materials

A list of instruments, laboratory fixtures, supplies and other materials needed. Note: Sources of supply can be listed in a subsection of Section 11 Appendices.

8 Procedures to perform in the lab

The first part should discuss any safety issues.

Step-by-step procedures then describe how to do much of the lab work. However, trying variations should be encouraged. (See also Section 10 for more far-reaching exploration.)

9 Data analysis and reflections about the results

An important goal is to yield, in most cases, a set of systematic quantitative results. How well does a technical system or process perform? Does the behavior conform to models developed in Section 6?

This is a place for critical reflection of how the lab process and technical design proceeded. Were there pitfalls or unexpected outcomes? How might models be improved? Where might issues exist that could be resolved with further development of the actual devices, instruments or processes?

Example code can be provided for data analysis. Independent additional coding and plotting should be encouraged.

10 Further exploration

Individual exploration of applications and improvements of the technical resources should strongly encouraged. Some suggested directons for exploration can be given, including ways to connect with other technologies.

11 Appendices

The sections can vary, but examples include:

Full classification details of the ancillary topics learned in this lab

More detailed modeling and analysis

Explanation of code algorithms

Sources of supply of materials

12 Bibliography

12.1 First reads

Books that give a good overview and introduction to the topic, with perhaps further practical lessons included.

e.g.

```
Alesina, I. and E. Lupton (2010), Exploring Materials: Creative De
sign For Everyday Objects (Princeton Architectural Press).
```

12.2 Desert-Island Book(s)

One or more books that could be the one(s) to have as a comprehensive reference on the topic if you were stuck on a desert island.

e.g.

```
Horowitz, P. and W. Hill (2015), The Art of Electronics, 3rd ed. (
Cambridge).
```

12.3 Journal literature, review articles, and websites

12.4 Technical books specific to this topic

(Back to top)

9. Learning resources: physical materials and instrumentation

An extremely important aspect of learning technical competencies is access to the necessary physical materials: electronics, sensors, instruments, raw materials, etc.

Kits exist for some types of competencies, such as the use of Arduinos and sensors for various projects.

Clever use of items readily available from ordinary retail stores including supermarkets, hardware stores, pharmacies, and computer stores can provide many items.

HOWEVER, learning opportunities can be greatly extended through the systematic and purposeful stockpiling of surplus specialized materials and instruments. University, government, and industrial labs are constantly converting technical equipment and supplies into surplus. Individual scientists, engineers, artists, and others want to donate materials they no longer need. (And example here in Colorado is a retired engineer who recently donated an entire van load of highly technical electronics components, metals, optical components, and instruments.)

A case must be made for such space to be provide for such stockpiles, since they are key to providing equitable and sustainable learning of technical abilities across the spectrum needed in 21st century society. This is especially important now since many traditional suppliers of such resources, such as Radio Shack and specialized hobby shops, are no longer in business. Ordering and fast shipment from online suppliers does not provide sufficiently varied, just-in-time hands-on contact with materials for vigorous exploration and prototyping.

An important feature of the 52-item classification system of section 4 is that it provides a robust framework for the physical storage of technical resources. I each of the 52 areas.

We prototyped such a stockpile and working environment and called it “The Hyperlab”. We hung signs from the ceiling to show students the location of the rich variety of resources for 52 areas of technical knowledge. It was an inventor’s paradise.

Unfortunately, the prototype implementation – once serving a large, diverse largely low-income k-12 schools –system was shut down in 2015. All of the resources of this Hyperlab – equivalent to several semitrailers in volume – are now in storage at personal expense ($1500 per month).

URGENT REQUEST
The following is a prospectus for Hyperlab 2.0. If you have the space and supporting staff (which can include students) to implement this, please contact Randy Tagg: most if not all of the stored resources might be available for your use. I might also consider relocating my personal 30,000 volume technical library if it can be secure and effectively support such a facility.

(Back to top)

Innovation Hyperlab 2.0

The purpose of the Innovation Hyperlab 2.0 is to enable people at many levels (K-12, college, graduate, professional) to use physics as a practical resource for innovation and design as well as for research. The larger aim is to ensure that physics as a discipline actively contributes to regional and national economic health, social equity, and sustainability. An earlier version of the lab has already served as a regional facility* and the new lab has the capacity to become a national facility as well as a model to be copied in whole or in part.

Resources and functions include:

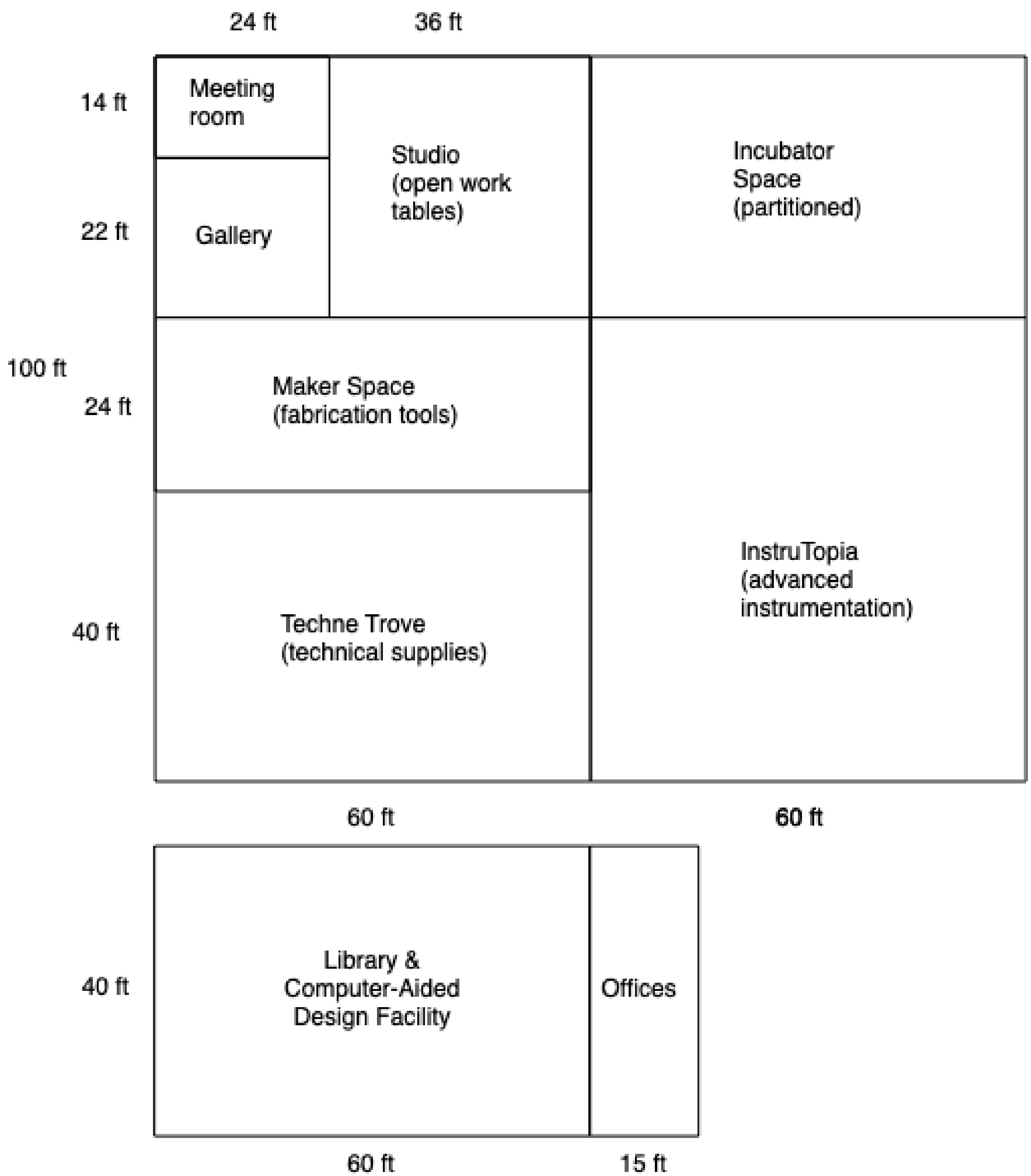
(1) A large physical inventory of technical artifacts, equipment and instruments useful for prototyping – a library of tangible components rich in their application of physics.
(2) A framework for making advanced and emerging technologies accessible to wider numbers of people: "Omnis Technologia Omnibus" (all of technology for everyone).
(3) An efficient means of triaging, storing, and managing surplus and donated equipment to "re-purpose" as resources for the development of innovative products and services, thus ensuring the sustainable and cost-effective use of technical assets in a region.
(4) An active and robust laboratory workspace for carrying out projects with the assistance of competent staff – related to but far more versatile than the concept of a "maker space". It would be like a versatile federal research lab (e.g. JPL) fitted into a warehouse.
(5) A virtual environment (web site) supporting on-demand learning or "pop up courses" to gain technical competencies – a powerful means by which people learn to use technologies and understand the underlying physics just when they need this knowledge in a project ("on demand").
(6) A center for creation and distribution to regional partners (schools, colleges, employers) of kits and other resource (including mobile labs) to support learning of technical competencies.
(7) A training facility for teachers who want to show their students the power of physics as both an applied science and a deeply fundamental approach to knowledge.
(8) A national training center for summer and winter break courses attracting people to a beautiful environment to learn how to use physics in innovation and design.
(9) A network of physics-based industry "intellectual sponsors" who guide the development of material assets and learning resources in the lab.
(10) A growing community of laboratory alumni who continue to share ideas and support each other in career advancement and technical innovation.

A major goal is to connect this lab to an emerging initiative encouraging physics programs nationally to develop curriculum that connects physics with innovation, community resilience, and entrepreneurship. The lab's founder, Dr. Randall Tagg, is collaborating with colleagues and staff in the American Physical Society, the American Association of Physics Teachers, and the Society of Physics Students.

Contact: randall.tagg@ucdenver.edu, 303-882-4348

* The original facility was called the Innovation Hyperlab, located next to Gateway High School. The lab now needs a new location and a new identity commensurate with its enlarged scope…one that goes well beyond K-12.

Innovation Hyperlab 2
Prospective Space Allocations



[(Back to top)]

10. Community impact

As systematic instruction occurs across a spectrum of competencies – technical, analytical, computational, statistical, and workflow – a primary benefit will be increased productivity and sense of efficacy of physics students. Early and progressively advancing exposure to technical resources and the skills to use them will enable students to engage more deeply in research and technical innovation. An accumulated personal repertoire of competencies will assist students with obtaining jobs and advancing their careers.

Beyond this, however, is a much wider potential for impact. First, of course, is the direct impact that physics students will have on society through their research, innovation, and skilled application of knowledge in the workplace. However, it should also be possible to extend opportunities to use the learning resources and the physical resources to the larger community. Working professionals broadening their skill base, small business owners developing products and services, adults pursuing hobbies and avocations, teachers expanding their resources for classroom use, artists creating works incorporating technical devices and physical phenomena, community groups solving specific local problems, and K-12 students wanting to explore science and technology are amongst those who could benefit.

We have already explored prototypes for such community engagement through

- the Community Prototyping Lab (2006-2008), created in partnership with a nonprofit that provided micro-loans to people seeking to create small businesses.
- The Innovation Hyperlab in Aurora Public Schools (2012-2015), a resource for classroom instruction at multiple schools through the district, host to an after-school student innovation academy, and teacher professional development.

Building on these examples, we hope ithat the powerful expression of physics through technical and other competencies can be something that can be learned by many citizens and used to develop resilient, sustainable, and equitable communities. A superb opportunity exists for talented physics students to aid in this community extension. We are pursuing one model of this in collaboration with the Society of Physics Students through an emerging organization called PSI*, which stands for Physics Student Innovators (*and alumni). This includes the Physics for Humans project that aims to make physics students more aware of the applications of physics to human needs.

See
https://www.spsnational.org/programs/outreach/psistar
and
https://www.spsnational.org/programs/outreach/physicsforhumans .

We encourage physics programs to participate and/or develop their own models for direct community impact.

(Back to top)