Physics Innovation and Entrepreneurship at a Liberal Arts University

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JLab Tech Transfer Workshop
Catholic University of America

WILLIAM & MARY
CHARTERED 1693

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Summary

Small Hall Makerspace at W&M

- The majority of physics students will enter a career that will require them to work on projects that are more similar to makerspace activities than to solving homework problems: we should provide them with the experiences to be successful in these kinds of projects.
- At a liberal arts institution without innovation and entrepreneurship activities, physics departments are uniquely placed to benefit at minimal cost from the possibilities of the maker movement.

The PIPELINE Network

- The PIPELINE Network is a three year project bringing together the efforts of six institutions to create and document new approaches to teaching innovation and entrepreneurship in physics, supported by the National Science Foundation Division of Undergraduate Education.

William & Mary: Liberal Arts University

Primarily undergraduate liberal arts institution

- No large medical or engineering program (mainly gen-ed and pre-med)

Primarily undergraduate liberal arts institution with

- Graduate programs in select departments with traditional strengths
  - PhD programs in History, American Studies (Jamestown, Williamsburg)
  - PhD programs in Physics, Applied Science (NASA Langley, Jefferson Lab)
  - Masters programs in Chemistry, Computer Science, Psychology,...
- Education school, business school (with entrepreneurship center)

Physics department at William & Mary

- Approximately 30 undergrad majors and 8 graduate students each year (recently cut in half by dean due to federal and state funding declines)
- Primary preparation for graduate school (as in most physics programs)
- Desire to prepare students better for the careers that await them

Careers for Physicists Primarily Outside Academia

Bachelors degrees in physics

- Only 1 out of 6 physicists gets a PhD degree (AIP SRC)
- All other physicists not included in "traditional physicists" interpretation

PhD degrees in physics

- Majority of permanent jobs are outside of academia
- About 1700 physics PhDs per year, significantly fewer jobs in academia
- All other physicists not included in "traditional physicists" interpretation

Mismatch between curriculum and reality of physics teaching

- How can we prepare our undergraduate and graduate students better for their most likely career?
- What opportunities can we provide as part of the curriculum?
- What opportunities can we provide outside the curriculum?

Careers for Physicists Primarily Outside Academia

Type of Employment of Physics PhDs by Employment Sector One Year After Degree, Classes of 2013 & 2014 Combined

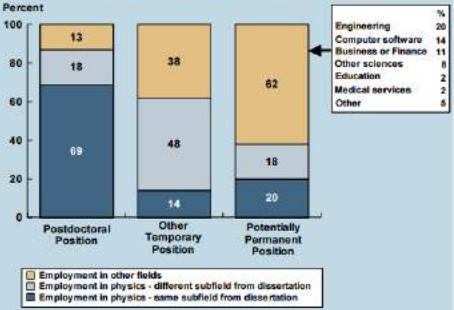
Sector of Employment	Initial Employment Type: Postdoc %	Potentially Permanent %	Other Temporary %	Overall %
Academic*	75	20	71	52
Private	1	70	18	31
Government	21	8	3	14
Other	3	2	8	3
	100%	100%	100%	100%

Note: Data only include US-educated physics PhDs who remained in the US after earning their degrees. Data are based on the responses of 655 postdocs, 523 individuals working in potentially permanent positions and 126 individuals working in "other temporary positions."

*The academic sector includes two- and four-year colleges, universities, and university affiliated research institutes.

http://www.aip.org/statistics

Employment Field of Physics PhDs One Year After Degree, Classes of 2013 & 2014 Combined



Note: Employment in physics means an individual's primary or secondary employment field was in physics or astronomy. Data only include US-educated PhDs who remained in the US after earning their degrees. Data are based on the responses of 419 postdocs, 297 individuals working in potentially permanent positions and 87 individuals working in "other temporary positions".

http://www.aip.org/statistics

Careers for Physicists Primarily Outside Academia

What skills are physicists lacking?[1]

- Ability to design a system, component or process to meet a specific need
- Ability to function on multi-disciplinary teams
- Ability to recognize value of diverse relationships (customers, supervisors, etc)
- Leadership skills
- Familiarity with basic business concepts (i.e. cost-benefit analysis, funding sources, IP, project management)
- Communication skills (oral and written), esp. how to tailor message to audience
- Real-world experience in companies before graduation
- Awareness of career paths outside of academia

[1] *Sources: ABET Survey of Applied and Engineering Physics Graduates, Kettering University; APS Workshop on National Issues in Industrial Physics, Industrial Physics Lunches.*

JLab's Lengthening Expt-Cycle Pushes Students Out Of Physics

Time frame from proposal to data-taking now several years

- None of the current Ph.D. students in my group will see data taking on the primary experiment they work on (MOLLER, maybe not even PREx-II which was an early off-ramp already)
- I simply cannot (get) support (for) a grad student exclusively to work on MOLLER or SoLID, let alone EIC.
- Scheduling is driving faculty to explore other projects, preferably in NP at other institutions (Mainz), preferably still in NP, but often elsewhere

Students are aware of this evolution and starting to consider this

- We used to get students interested in training big data; not anymore...
- Then we got students interested in data taking and collaborative research; not anymore...
- Even students performing graduate research now are looking for pivot to technology applications

What Opportunities Can We Provide?

Inside the curriculum: Engineering Physics and Applied Design

- New undergraduate track within physics, major with applied science
- Initial (freshmen/sophomore) coursework heavily based in physics
- Advanced courses in applied science and engineering
- Advanced courses in business and entrepreneurship
- Full curriculum moving to implementation, pilot courses underway, first cohort 2018

Outside the curriculum: Small Hall Makerspace

- Student-accessible campus hub (or network of hubs) that functions as design space, laboratory, project planning, business development
- Space for out-of-class activities which could be curricular or not

Engineering Physics and Applied Design I

Minimal Physics Curriculum

- PHYS 101/102 – Introductory Physics with labs
- PHYS 201 – Modern Physics
- APSC 231 – Intro to Engineering and Design
- PHYS 208 – Classical Mechanics I
- PHYS 313 – Quantum Mechanics I
- PHYS 401 – Electricity and Magnetism I
- PHYS 251/PHYS 252 – Upper level labs
- PHYS 314 – Quantum Mechanics II
- PHYS 402 – Electricity and Magnetism II
- PHYS 403 – Classical Mechanics II
- PHYS 471/472 Senior Design Capstone Project

Engineering Physics and Applied Design II

Rendering/Simulation Labs

- Materials characterization
- Optics and optoelectronics
- Structural mechanics, fluid mechanics

Business/Entrepreneurship Courses

- Project management
- Intellectual property
- Design thinking and customer discovery
- Business plans (business model canvas, lean launchpad)

Engineering Physics and Applied Design III

Senior Design Capstone Project

- Group project (3-5 students) directed at a product (MVP)
- Requires: science plan, management plan, business plan
- Project ideas from industry and from SBIR, STTR, BAA
- Similar courses in development in Biology and CompSci as implementation of new COLL 400 capstone requirement

Dedicated spaces for these student projects

- Entrepreneurship Center in School of Business
- Skills training through Small Hall Makerspace

Educational Goals: Small Hall Makerspace

Small Hall Makerspace

- Formed in Fall 2013 for interdisciplinary team-based projects
- "We provide the tools, students bring their creativity"

Encourage failure as fundamental to innovation

- Instill "fail early, fail often" attitude
- No cost to failure (whether financial or to GPA) in makerspace projects

Value prototyping process over the solution itself

- Students have strong theoretical basis but weaker practical experience
- Students are used to getting to "right" answer on straightforward path
- Laboratory exercises (even if self-guided and not recipe-driven) still often follow a predictable path towards a single solution

Small Hall Makerspace at W&M

Electronics and computation workshop

- Raspberry Pis, Arduinos, Oculus Rift VR, SMD reflow oven
- Server rack (old lattice QCD nodes)

Rapid prototyping shop

- 3D printers, laser cutters (incl. 1.5 mm steel capable), vacuum thermoformer
- Actobotics and 80/20 mechanical erector set

Student machine shop

- Manual drill press, milling machines, lathes
- CNC mill and lathes, 3 axis $2' \times 3'$ CNC

Total investment: $200k, primarily internal funds

Small Hall Makerspace at W&M

Rapid prototyping and electronics shop (3D printers not shown)

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Student machine shop (under supervision only)

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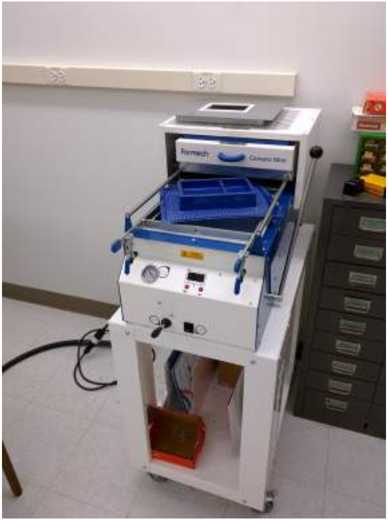
Larger equipment: cluster, thermoformer, laser cutters



Small Hall Makerspace at W&M

Larger equipment: cluster, thermoformer, laser cutters

Reception in the Department

Current feelings among faculty are uniformly positive

- Integral part of department with integration of makerspace in courses, outreach, student activities, faculty development
- Connection to other departments for both students and faculty

Faculty use of makerspace resources (somewhat unexpected)

- Heavy use of 3D printers and laser cutter (lens holders, mylar clamping rings for gas Cerenkov detectors)
- Source of students with expertise with Raspberry Pi and Arduino
- Resulted in co-purchasing agreements for professional-grade equipment

Makerspace Projects

Proposal submission

- Request for proposals once per semester
- Following the Heilmeier Catechism (DARPA)
- Includes narrative, schedule and project budget
- $500 for single student PIs, $1k for interdisciplinary student PIs

Selection

- Students learn about conflicts of interest, feedback, proposal writing
- User board makes recommendation, coordinators draw funding line

Spending

- Department spends on behalf of the students

Curricular Activities: Robo-Ops Competition

Participation in national competition

- National NASA/National Institute of Aerospace tele-robotics competition
- Objective: build a tele-robotic rover system to retrieve colored rocks in Johnson Space Center's Rock Yard, operated completely from home institution
- Participation as demonstrator team in collaboration with U Nebraska Mech-Eng and NASA Langley Research Center, with same budget as university teams (large engineering schools)
- Multidisciplinary group of 15 students, between 1 and 3 credits
- Makerspace contribution: build a computer vision system to recognize, identify, map, and plan retrieval of colored rocks in a martian/lunar desert/crater landscape
- Disciplines: physics, computer science, math, geology, business

Curricular Activities: Robo-Ops Competition

Experiences

- Rapid prototyping and agile development, both hardware and software
- Multiple W&M sub-teams addressed different aspects with separate team leads: excellent experience for students and learning experience for instructor

Robo-Ops competition on May 24, 2016

- Rover at NASA Johnson Space Center operated from NASA Langley Research Center mission control room
- Finished third in field of 8 competing teams (first prize: "Rovie McRoverface" from U Oklahoma)

Curricular Activities: Robo-Ops Competition

Demonstration run at NASA Langley Research Center

Curricular Activities: Senior Capstone Design Project

Alternative to senior research

- Pilots through Robo-Ops, medical physics development, systems integration in neutrino physics
- Agile project management with support from some of the Agile Manifesto authors in conjunction with defense contractors, engineering consulting company, Anthem mob dev, NASA LaRC

Spring 2018: NASA Lab 77 Agile Project (starts next week)

- NASA LaRC Lab 77: CubeSat incubator, technology development hub
- 5-person group of students (including business, compsci, physics), pick problem, develop solution, build MVP
- “Rent a scrum-master” through Berkana Enterprise Consulting, Anthem

Project Showcase: 3D-Printable Scintillator Photopolymers

Development of transparent scintillating 3D-printer photopolymer

- UV stereolithography using custom-formulated photo-resin (scintillator compound embedded in cross-linked polymer matrix)
- Precision (using small scale 3D printer) of sub-mm scale
- Light yield of about 1/3 compared to standard BC-408
- Completed studies of long-term mechanical and optical stability, strength, efficiency

Fail early, fail often, or languish

- Project that did not rise to high enough TRL quickly enough before it started negatively impacting PI's career prospects
- Interdisciplinary projects (chemistry, nuclear physics) are encouraged everywhere but have an even harder time getting funded or recognized; they are also the natural nexus for new developments

Project Showcase: 3D-Printable Scintillator Photopolymers

Project Showcase: Bio-Degradable Plastics

Prototyping of bio-degradable components in marine environment

- Collaboration with Virginia Institute of Marine Sciences (VIMS)
- Lost crab traps (steel wire) remain active for long time (loss 10%)
  - Cycle of death: crabs are carrion-feeders
- "Escape hatches" from bio-degradable plastic that disintegrates in months render the crab traps inactive

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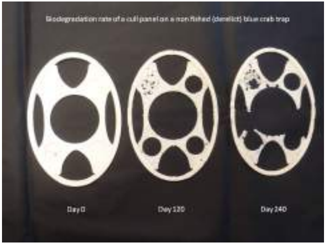

Project Showcase: Bio-Degradable Plastics

Development of PHA 3D printer filament (similar to PLA)

- PHA = poly-hydroxy-alkanoate (similar to PLA biopolymer commonly used for 3D printing)
- Three undergraduates, one graduate student in physics and applied science
- Makerspace equipment: two polymer filament extruders and hardware for coiling jigs
- PHA absorbs excess nutrients in water: filtration mats in ponds, lakes
- Commercialization through VIMS: Green Ammo (PHA wadding), working on erosion-prevention run-off construction mesh

Other printer filament development by students and researchers

- Graphene-infused nylon filament for oil pipes
- Tungsten-infused ABS filament for radiation shielding

Project Showcase: SharkDuino

Accelerometer/gyro data-logging tag based on Arduino

- Collaboration with Virginia Institute of Marine Sciences (VIMS)
- Study of sandbar sharks and other species (Atlantic sturgeon) in Chesapeake Bay
- Off-the-shelf tags are expensive ($1k/ea) and not rechargeable or reusable
- Idea to use commercial off-the-shelf Arduino pro mini to read custom shields
    - OpenTag is commercial tag that is “open in name only”

Project Showcase: SharkDuino

Development by undergraduate students in Small Hall Makerspace

- VIMS researchers, W&M Committee on Sustainability supports students, Small Hall Makerspace invests in equipment
- Two undergraduates: physics and computer science sophomores
- Makerspace equipment: surface mount soldering reflow oven, PCB board development etching chemicals (approximately $1k)
- First data collected this summer at Eastern Shore Lab for marine ecology

Sharks were instrumented with accelerometer/gyro board

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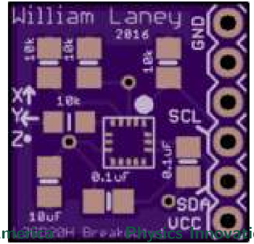

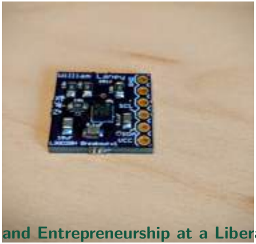

Equity and Inclusion in Entrepreneurship

Few visible entrepreneurs in top industry positions

- Only 23 women are CEOs in S&P 500 (4.6%), 8 in S&P 100 (July 2016)
- Persistent perception that successful entrepreneurship is for men

Equity and inclusion issues in physics[2]

- Fraction of physics bachelor degrees earned by women less than 20%
- Only 2.2% of physics bachelor degrees earned by African Americans

[2] *APS Education & Diversity, 2015*

Equity and Inclusion in Entrepreneurship

Combination of two problematic fields requires some thought

- Careful attention to how student project groups are composed
- Gentle nudges to consider actively attracting students from many backgrounds
- Zero-tolerance policy for any language or behavior that affects welcoming atmosphere
- Active attempts to use outreach activities as a way to engage students who may not feel comfortable in typical makerspace
- Hiring of undergraduate assistant coordinators with connections to other departments (current undergraduate coordinator organized Dear Rosalind makerspace club that explicitly addresses equity)

Institutional Barriers Against Physics I&E I

Missing intra- and external institutional links

- Silo-ization of academia: strict separation between A&S depts, VIMS, School of L/B/Ed (currently setting up industry partnership forum across A&S depts, School of B; already exists at VIMS)
- Course credit revenue-sharing firewall between School of Business (entrepreneurship) and School of Arts & Sciences (physics)
  - Entrepreneurship Center instructor gets flak from their dean when giving overrides to physics students
- Tech transfer office not a known resource for most faculty (no active reaching out from TTO)
- Most faculty allergic to learning new things (intellectual property, small business management, project management), let alone including it in teaching (APS PIPELINE network attempts to address this)

Institutional Barriers Against Physics I&E II

Absent alignment mechanism

- Lack of history in engineering, entrepreneurship and institutional focus on individual liberal arts: often merely a failure of imagination (our biggest I&E dept is arguably government through US-AID)
- Lack of strong connections with industry (considering APS Local Link for Hampton Roads centered around JLab)
- No incentives for physics faculty who are evaluated on research, not tech development (in contrast with engineering)
- Early "valley of death" between research and seed investor funding, compounded by requirements on cost-sharing for VA state grants (CRCF, CIT, VRIF) which require previous federal grants; most of the previous projects are funded through our university's own 'angel investor' (IDC return on my own grants); this is a question of getting to high enough TRL for further funding, applied research resulting in MVP

What I Am Interested In Working To Achieve? I

Current efforts

- Makerspaces in physics education
- Engineering Physics and Applied Design tracks in physics
- Connections between physics and business community
- Forming physics I&E community through PIPELINE, AAPT, APS

Senior capstone commercialization projects for Jefferson Lab

- Combination of Physics EPAD and Entrepreneurship Center field consultancy
- Yearly yearlong opportunity for evaluation of large number of idea(let)s

What I Am Interested In Working To Achieve? II

Training for Jefferson Lab community

- Jefferson Lab runs projects like NASA in the 80s, not like a startup
- Large collaborations are often lead by terrible project managers
  - Agile project management training for any group leader
- New developments at Jefferson Lab (affiliated institutions) not commercialized
  - JSA IF program for up to $20k level to bring to TRL4?

APS Local Link centered around Jefferson Lab

- Connecting industry leaders with lab-affiliated researcher, push-pull of ideas and applications
- Pipeline for talent to industry, commercialization efforts for JLab

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