

# Show Me the Money!

## Economic and Policy Aspects of Open Source Scientific Hardware

Joshua M. Pearce

Richard Witte Professor of Materials Science & Engineering  
Professor Department of Electrical & Computer Engineering  
Director: Michigan Tech Open Sustainability Technology (MOST) Lab  
Michigan Technological University

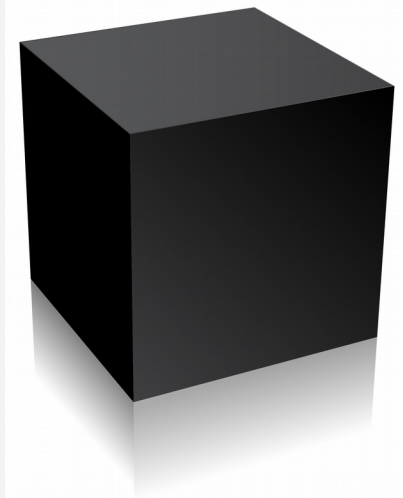
Visiting Professor Équipe de Recherche sur les Processus Innovatifs (ERPI), Université de Lorraine, France  
Visiting Professor of Photovoltaics and Nanoengineering, School of Electrical Engineering, Aalto University, Finland  
Editor-in-chief *HardwareX*



# Most Scientific Equipment Spending Subsidizes Proprietary Black Boxes

NSF MRI Budget Last Year

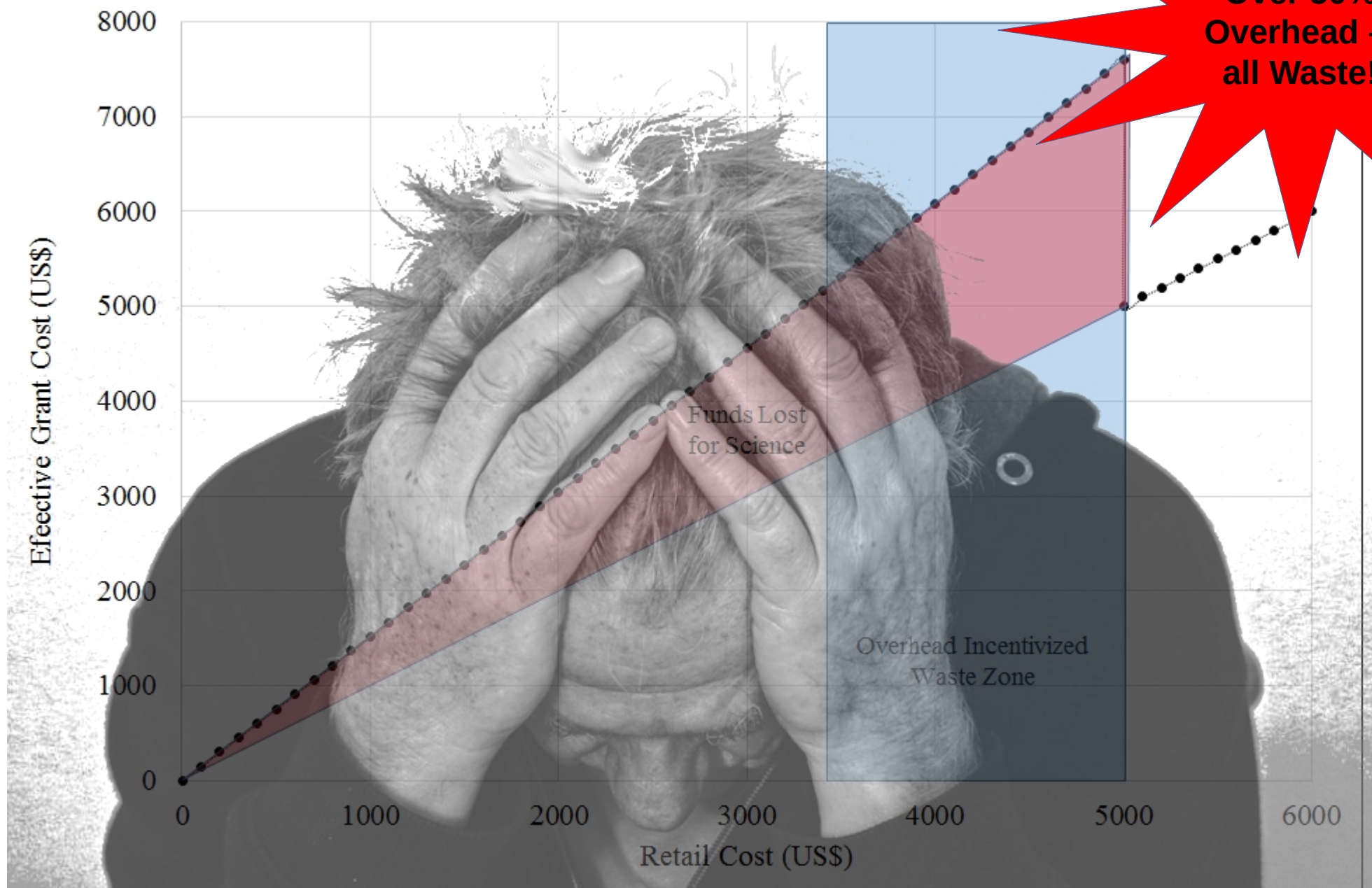
Total, Research and Related Activities	5,662.96
Education and Human Resources	823.47
Major Research Equipment	223.23 MILLION!
Agency Operations and Award Management	336.89
Inspector General	15.35
National Science Board	4.1
TOTAL NSF	7,066.00



**Results: High costs/inaccessible to all but wealthy, wasted time on grants, replication crisis, slow sci-tech development, wasted funds, and wasted time!**

**Don't  
waste  
time.**

- > Productivity Measured by “Research Expenditures” - Overheads
- > Arbitrary \$5,000 lower limit for defined equipment purchases in U.S. results in millions of dollars of lost science funding/year.



# **Recommendation 1**

**Deny all overheads  
for university  
research**

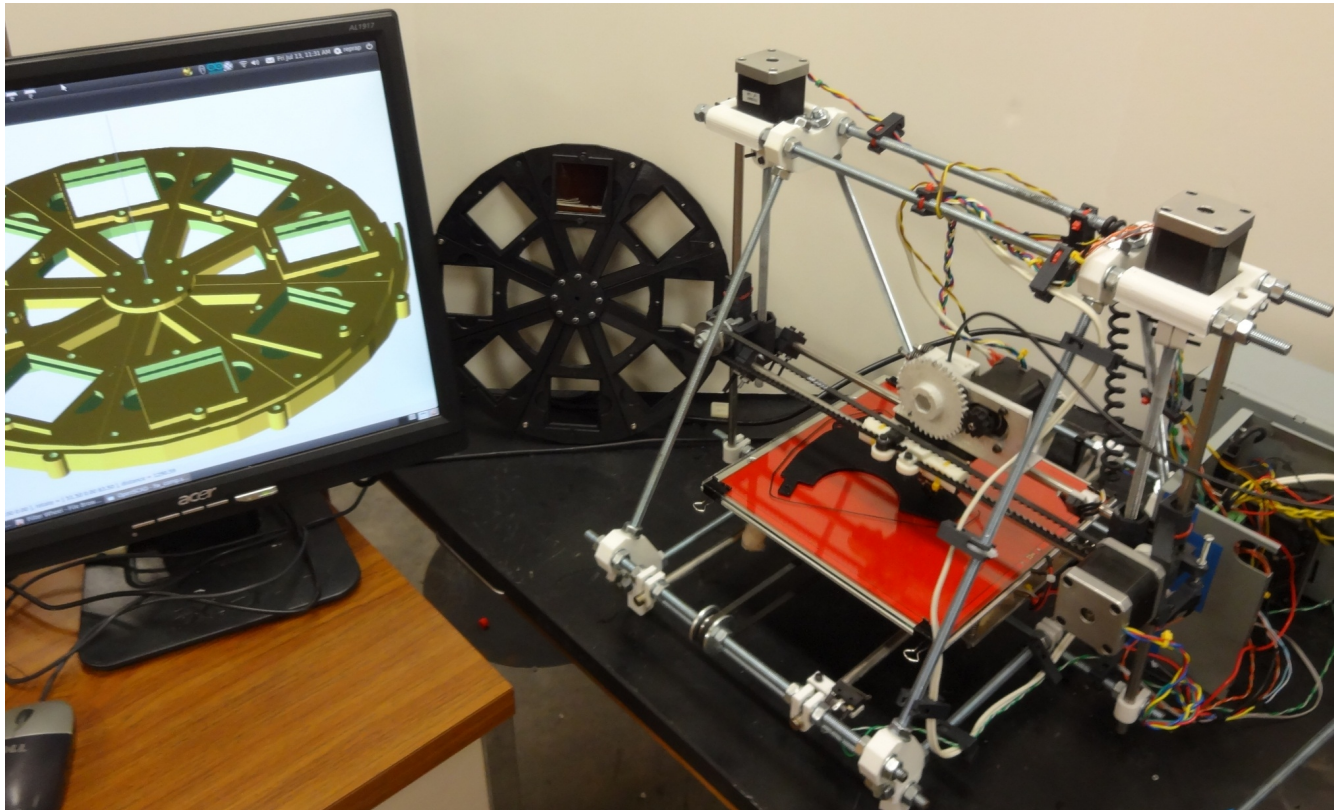
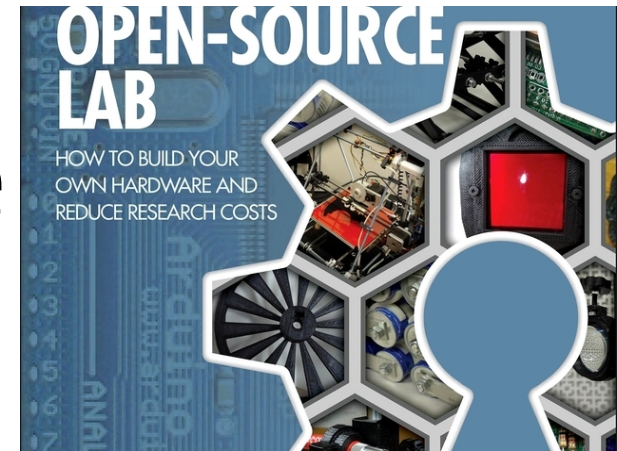
**or**

**Tie overheads to  
open source release  
of all technology**





# Now: Open Source Hardware



**Linux,  
OpenSCAD,  
RepRap,  
Arduino,  
OS automated  
filter wheel**

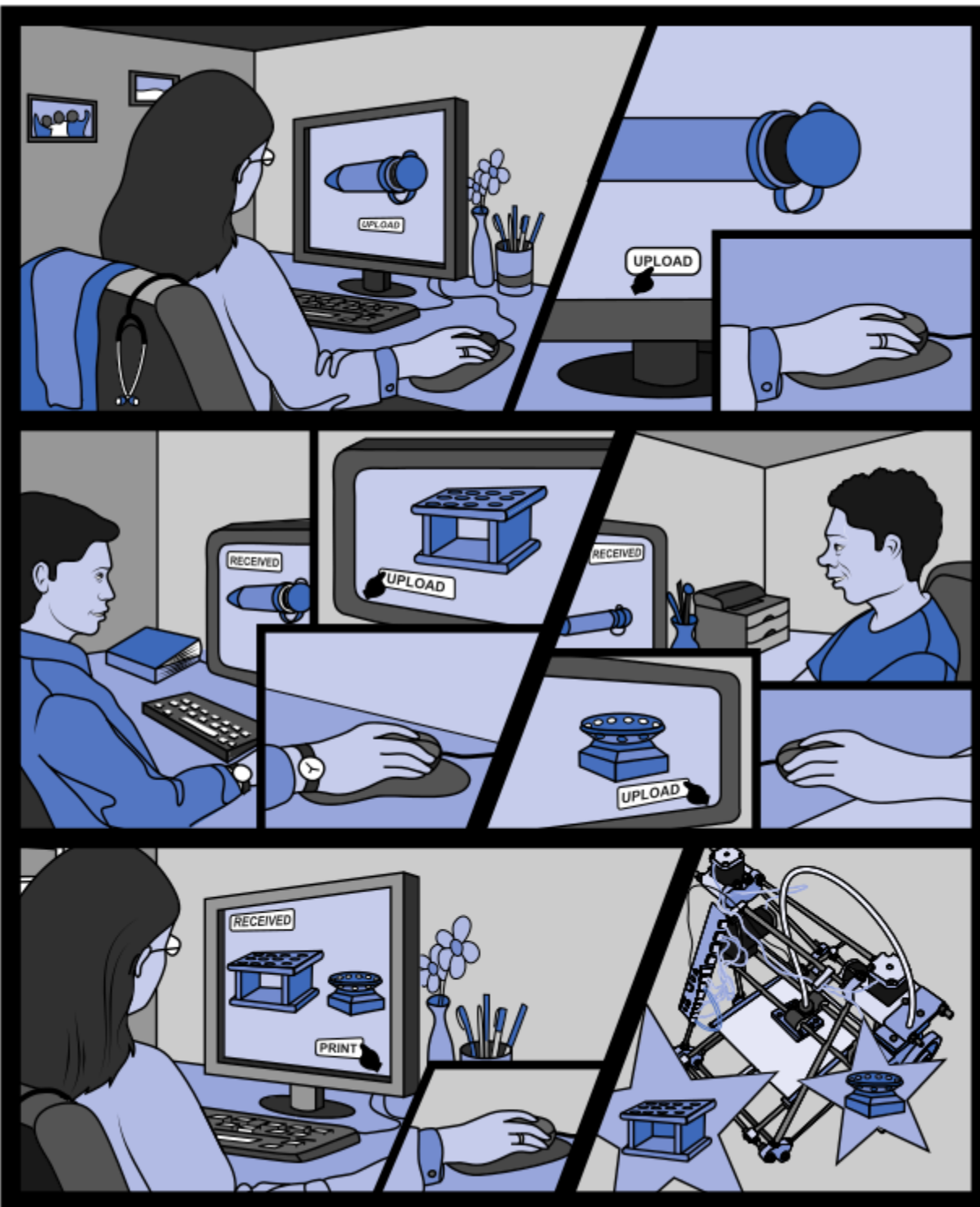
Pearce, J. M. 2012. "Building Research Equipment with Free, Open-Source Hardware." *Science* **337** (6100): 1303–1304.



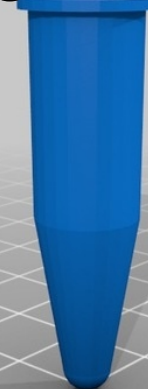
Appropedia.org/Pearce

# FOSH + Digital Fab in Science

## How it Works



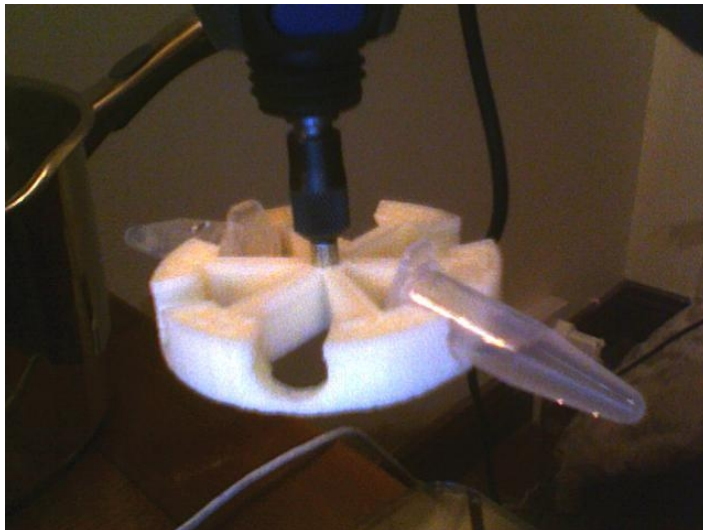
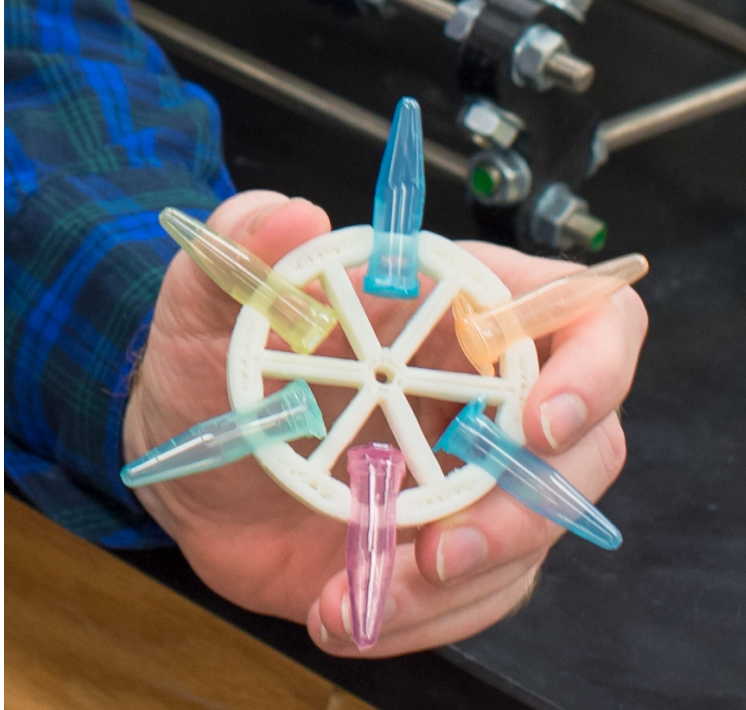
Simple Designs → Complexity



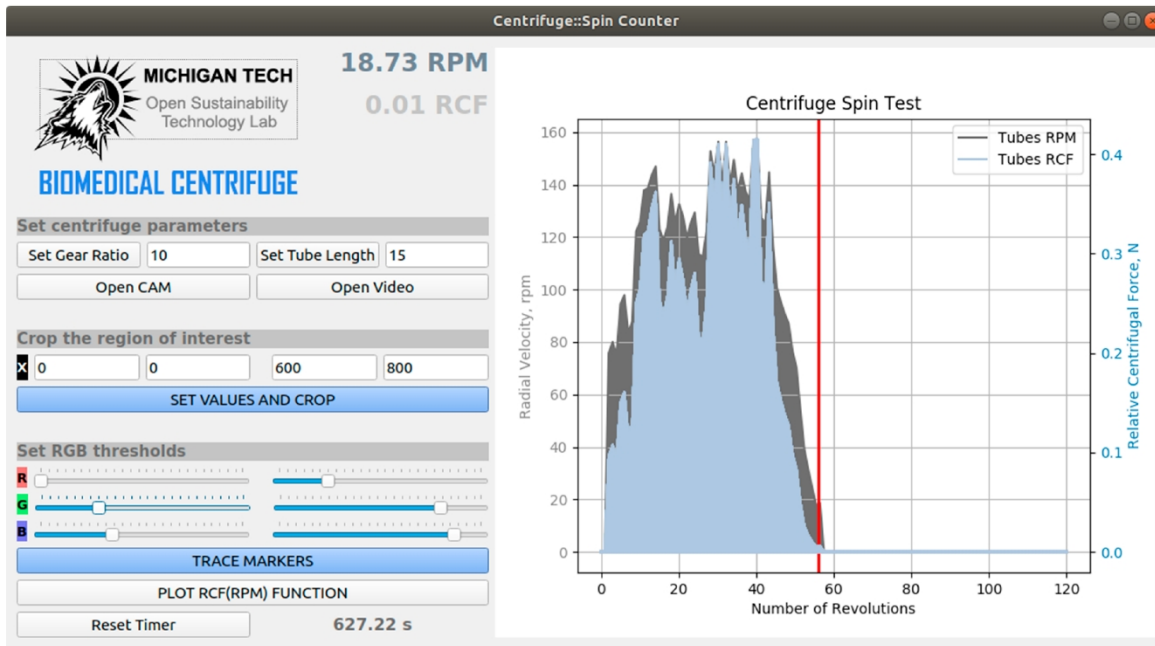
More Sharing = More Rewards



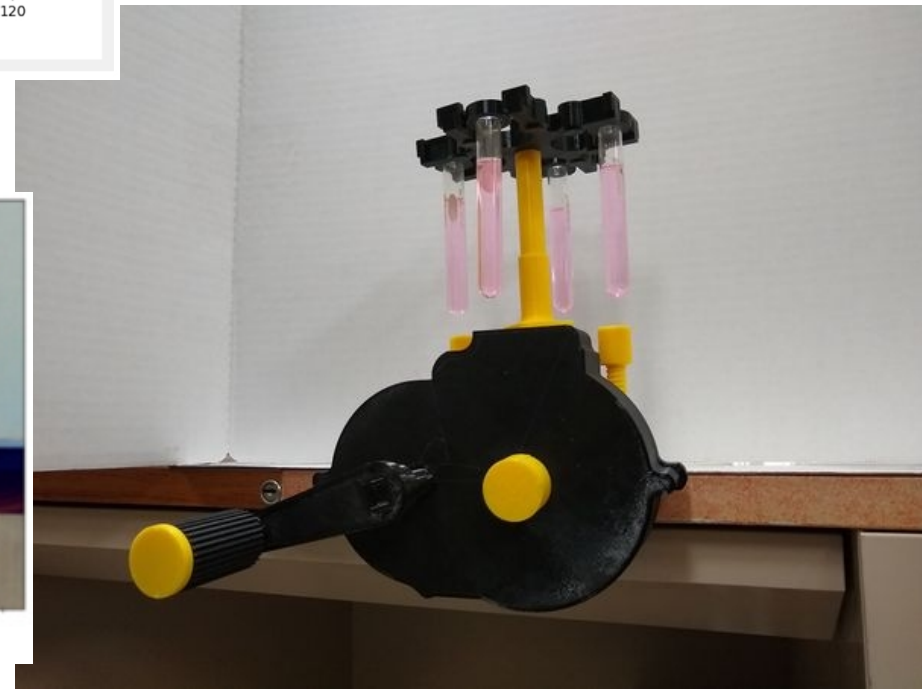
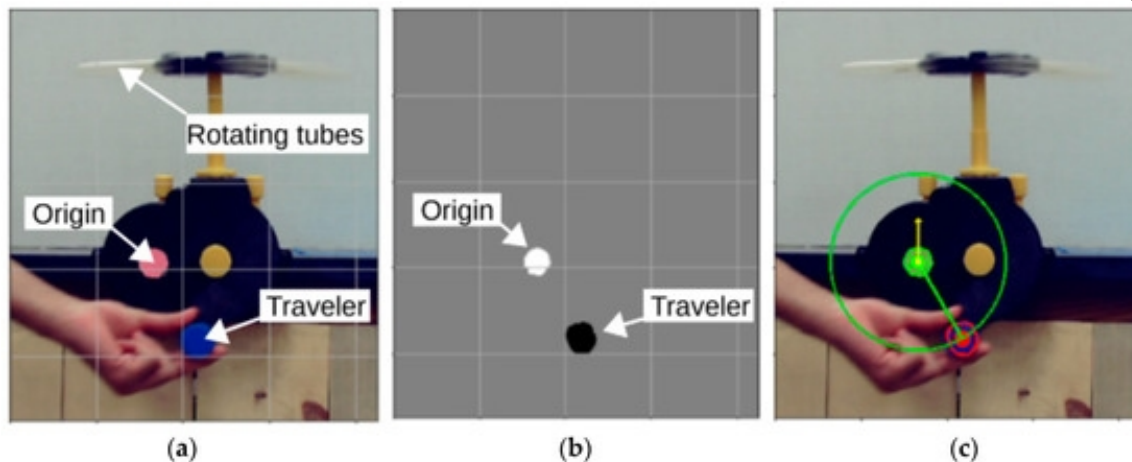
# Centrifuges



# All 3-D Printed Centrifuge

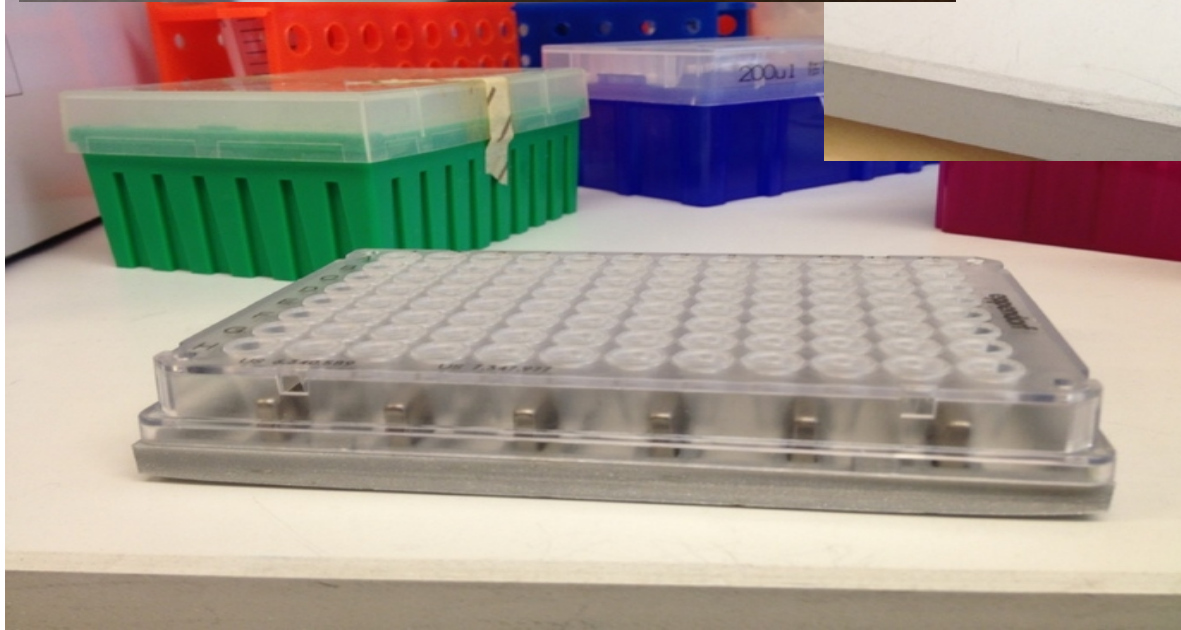
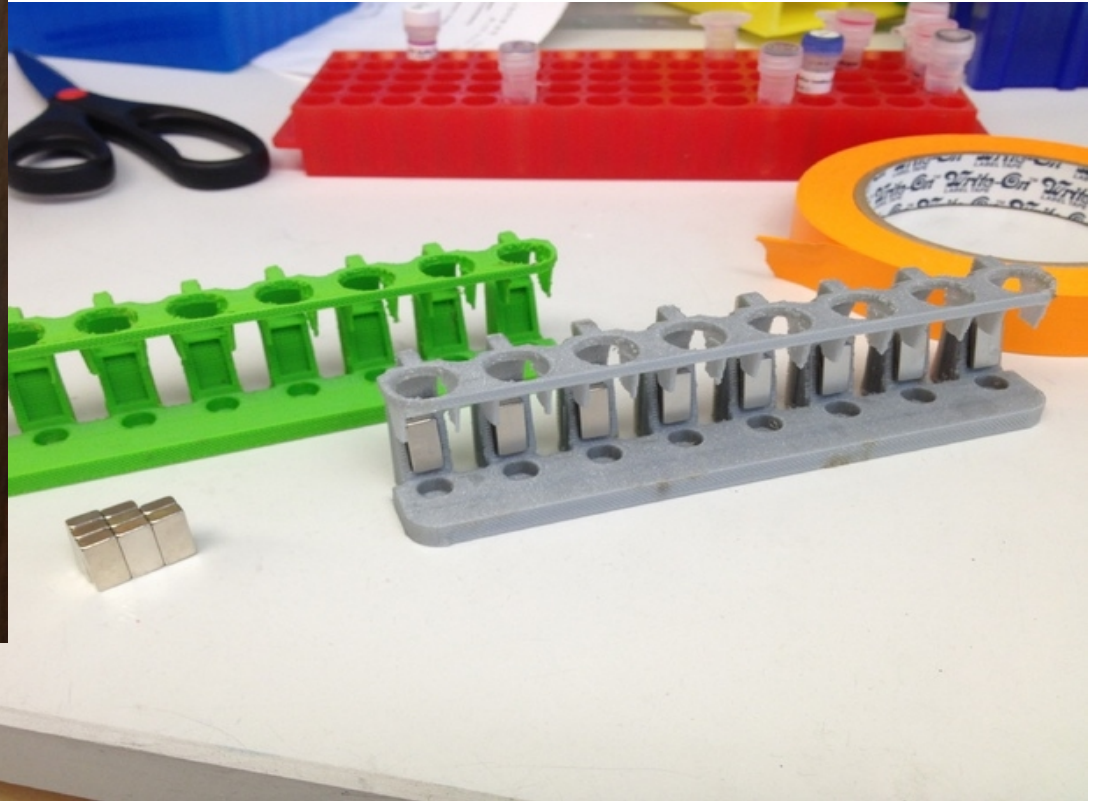
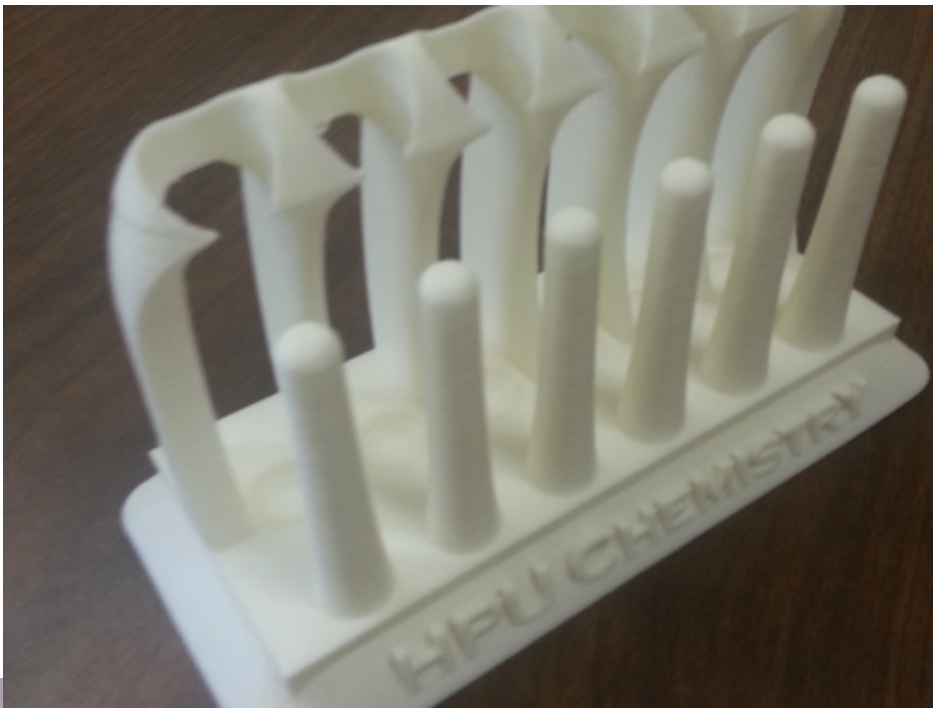


Salil S. Sule, Aliaksei L. Petsiuk and Joshua M. Pearce. Open Source Completely 3-D Printable Centrifuge. *Instruments* 2019, 3(2), 30; <https://doi.org/10.3390/instruments3020030>





# Test Tube and Magnetic Racks



**Justify a 3D printer  
cost making 1 rack;  
or a fancy one for 2!**





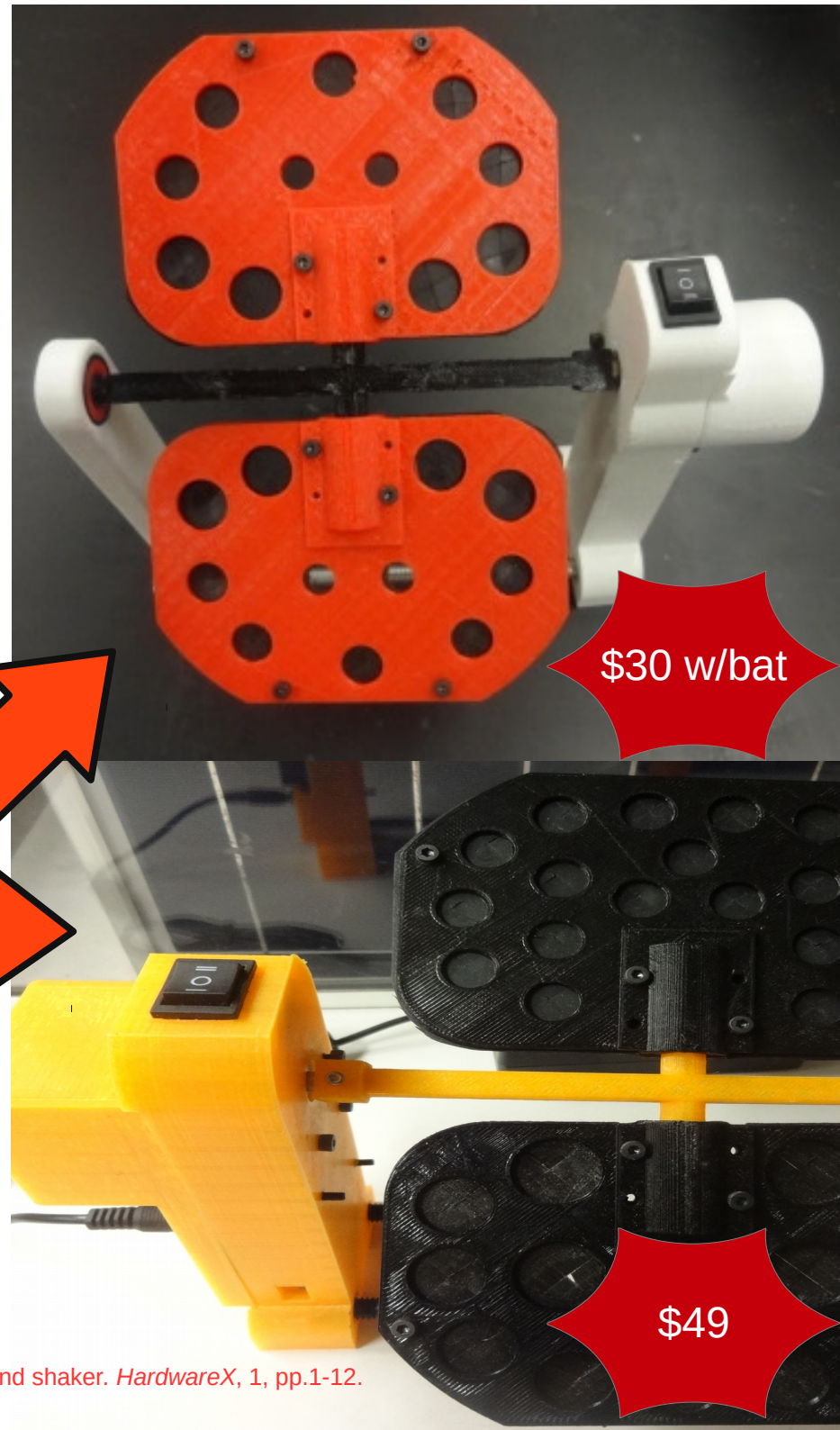
# *Journal for Open Hardware and HardwareX*

**Example: Shaker/Mixer**

**\$500 with no shipping closest equivalent**

**\$1,000 with shaking**

**HardwareX** NEW JOURNAL  
Now accepting submissions

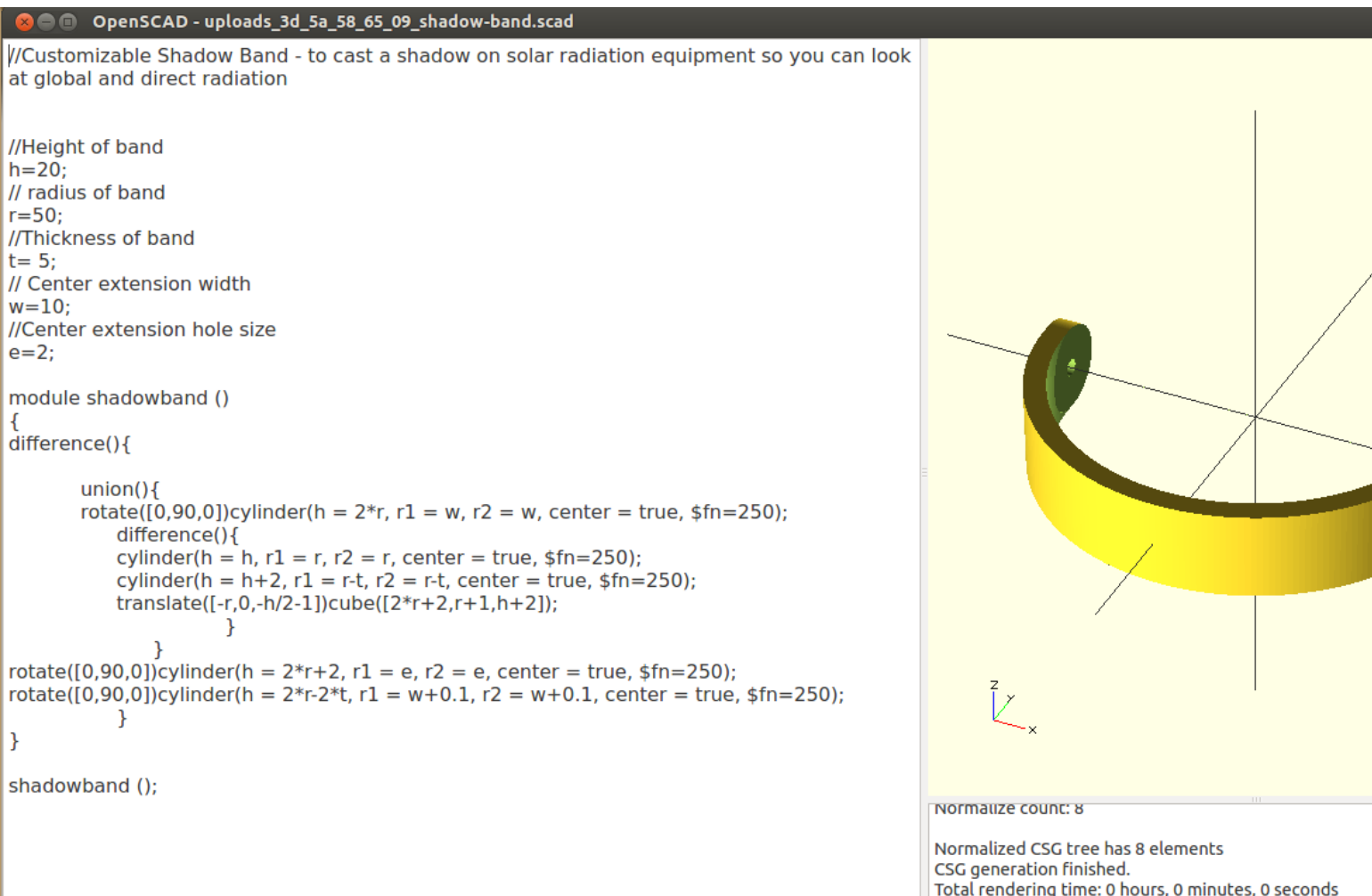


**\$30 w/bat**

**\$49**

# Customization is Easy : OpenSCAD

## Parametric Shadowband for Pyranometer



# Even Easier: Customizer

## Customizable Perforated Cylindrical Plate



### Parameters

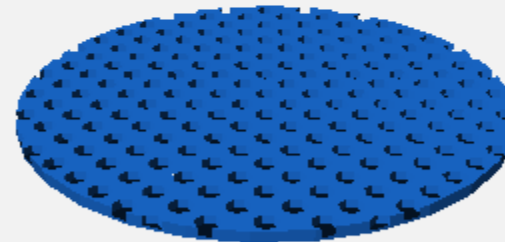
**D Paper** Defines the diameter of filter paper for your funnel

**T Plate** Defines the thickness of the perforated plate

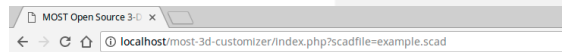
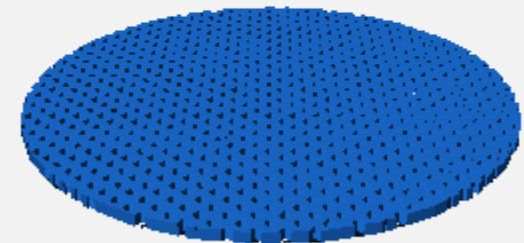
**A** Defines the area of the array

**R** Defines the radius of the holes

**S** Defines the spacing of the holes

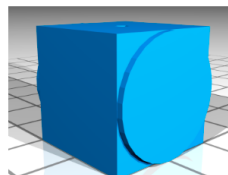


Nilsiam, Y. and Pearce, J.M., 2017. Free and open source 3-D model customizer for websites to democratize design with OpenSCAD. Designs, 1(1), p.5.



**FREE OPEN SOURCE  
3-D CUSTOMIZER**

File: example.scad



Cube Size

Large

Hole Diameter

5

Hole Depth // How deep should the center hole be?

5

Show Wheels

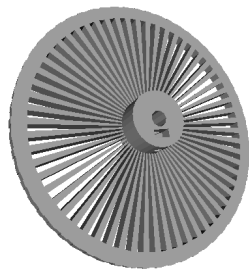
yes

Wheel Thickness // How thick should the side wheels be?

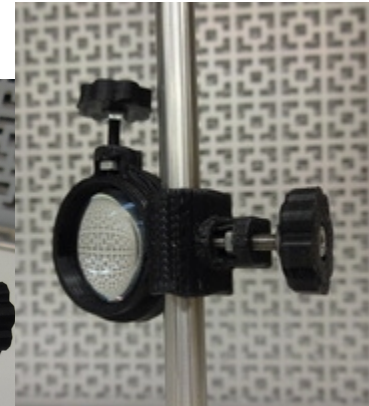
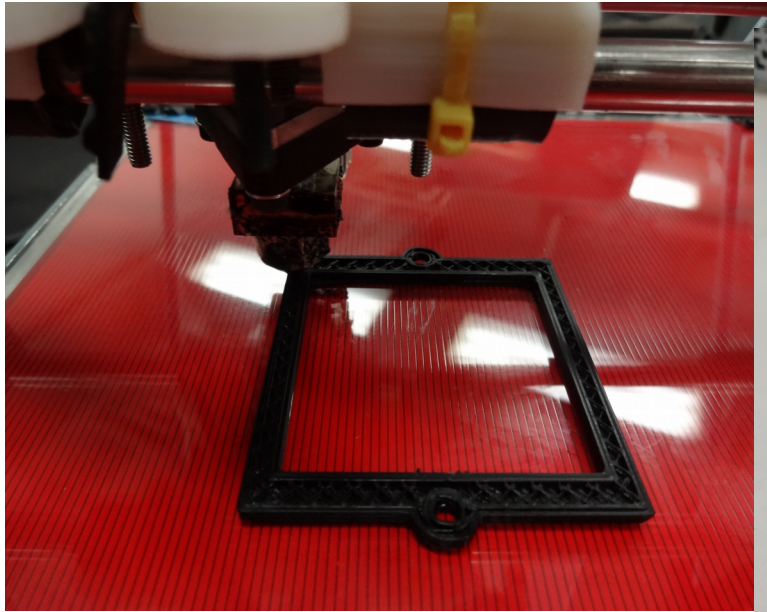
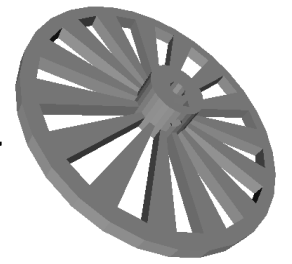
7

Save

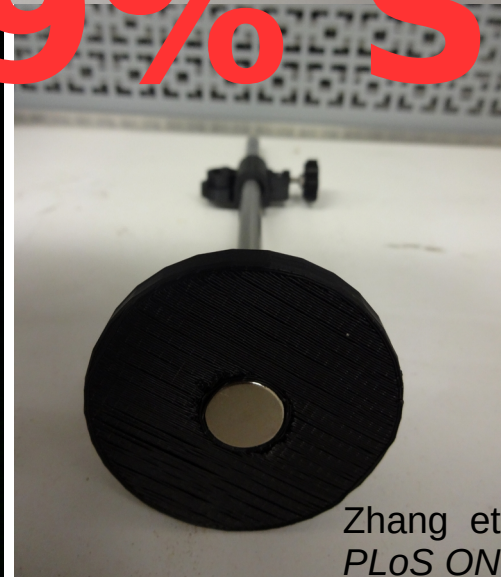




# Open Source Optics Library



**97-99% Savings**



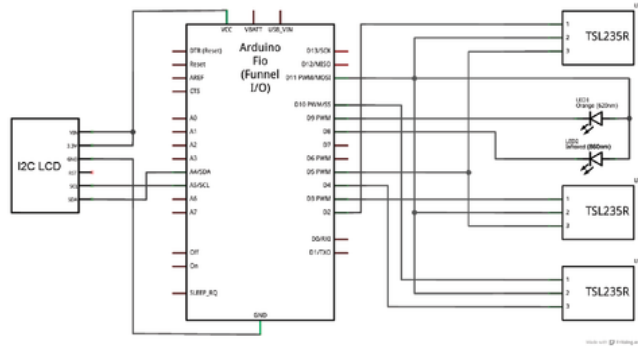
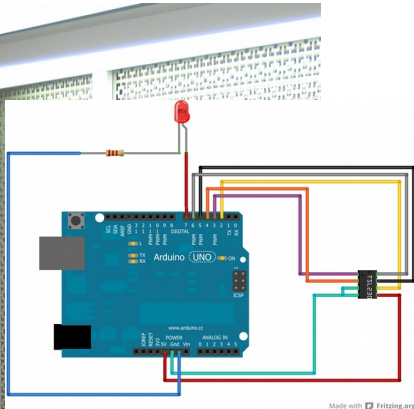
Optical rail sells for \$380/m.  
Open beam only costs \$12/m

Zhang et al. Open-Source 3D-Printable Optics Equipment.  
PLoS ONE 8(3): e59840



# Colorimeter + OS Nephelometer for Turbidity...Mobile, Parametric

Save \$2000!



B. Wijnen, G. C. Anzalone, J. M. Pearce, Open-source mobile water quality testing platform. *Journal of Water, Sanitation and Hygiene for Development*, 4(3) pp. 532–537 (2014).

Anzalone GC, Glover AG, Pearce JM. Open-Source Colorimeter. *Sensors*. 2013; 13(4):5338-5346.

Save \$1000!



Appropedia.org/Pearce





# Nitrate Testing: Commercialized FOSH



Wittbrodt BT, Squires DA, Walbeck J, Campbell E, Campbell WH, Pearce J.M. (2015) Open-Source Photometric System for Enzymatic Nitrate Quantification. *PLoS ONE* **10**(8): e0134989.

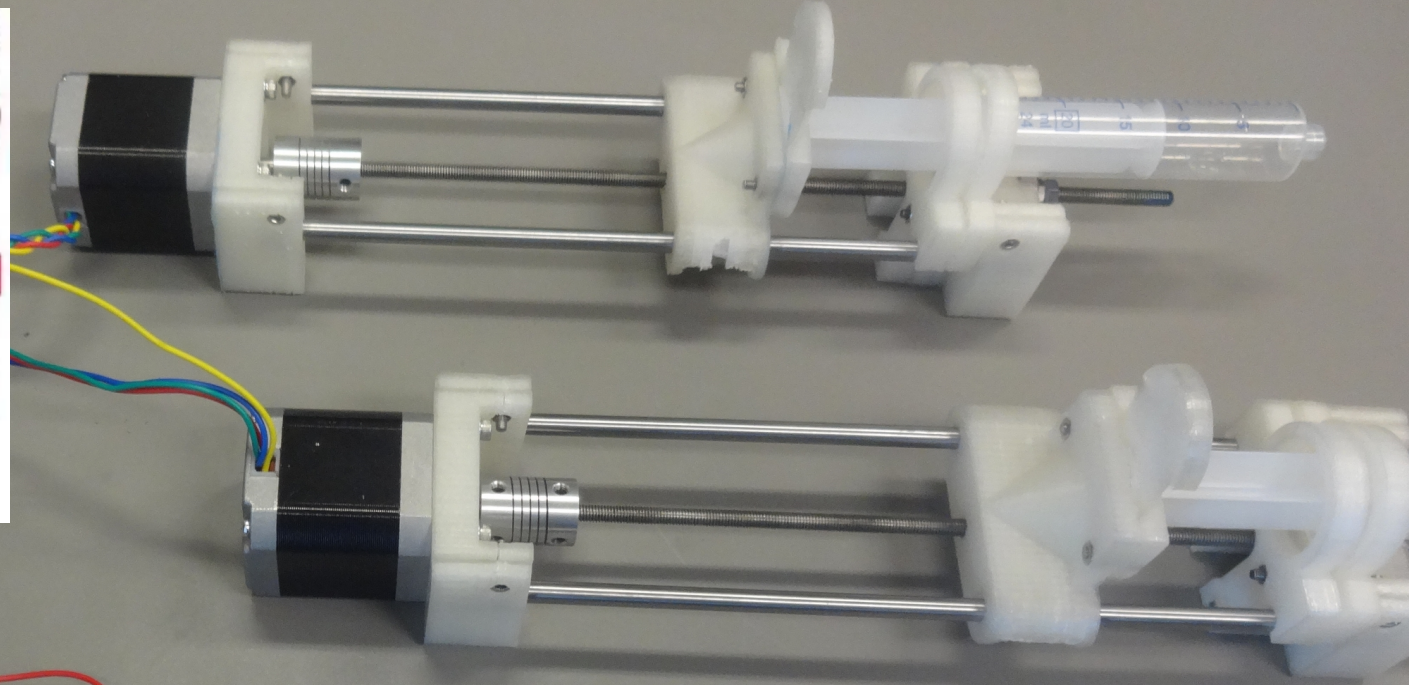
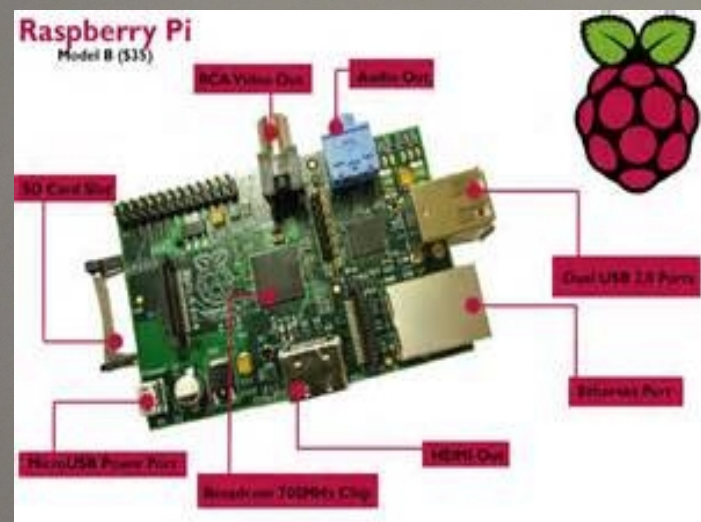


Appropedia.org/Pearce



# Making Tools for Every Application

## Bespoke OS Syringe Pumps



Bas Wijnen, Emily J. Hunt, Gerald C. Anzalone, Joshua M. Pearce, 2014.  
Open-source Syringe Pump Library  
PLoS ONE 9(9): e107216

**Save \$150-\$2,400  
Each!**



# of FOSH for Science

Syringe Pump: Savings \$153-\$2,442/pump (single,double)

Designs downloaded >1k times by Feb 2015

**Downloaded Substitution Value \$168k-\$2.5m**

Assume \$30k for development, 52% overhead

**ROI of 750%-12,000%**

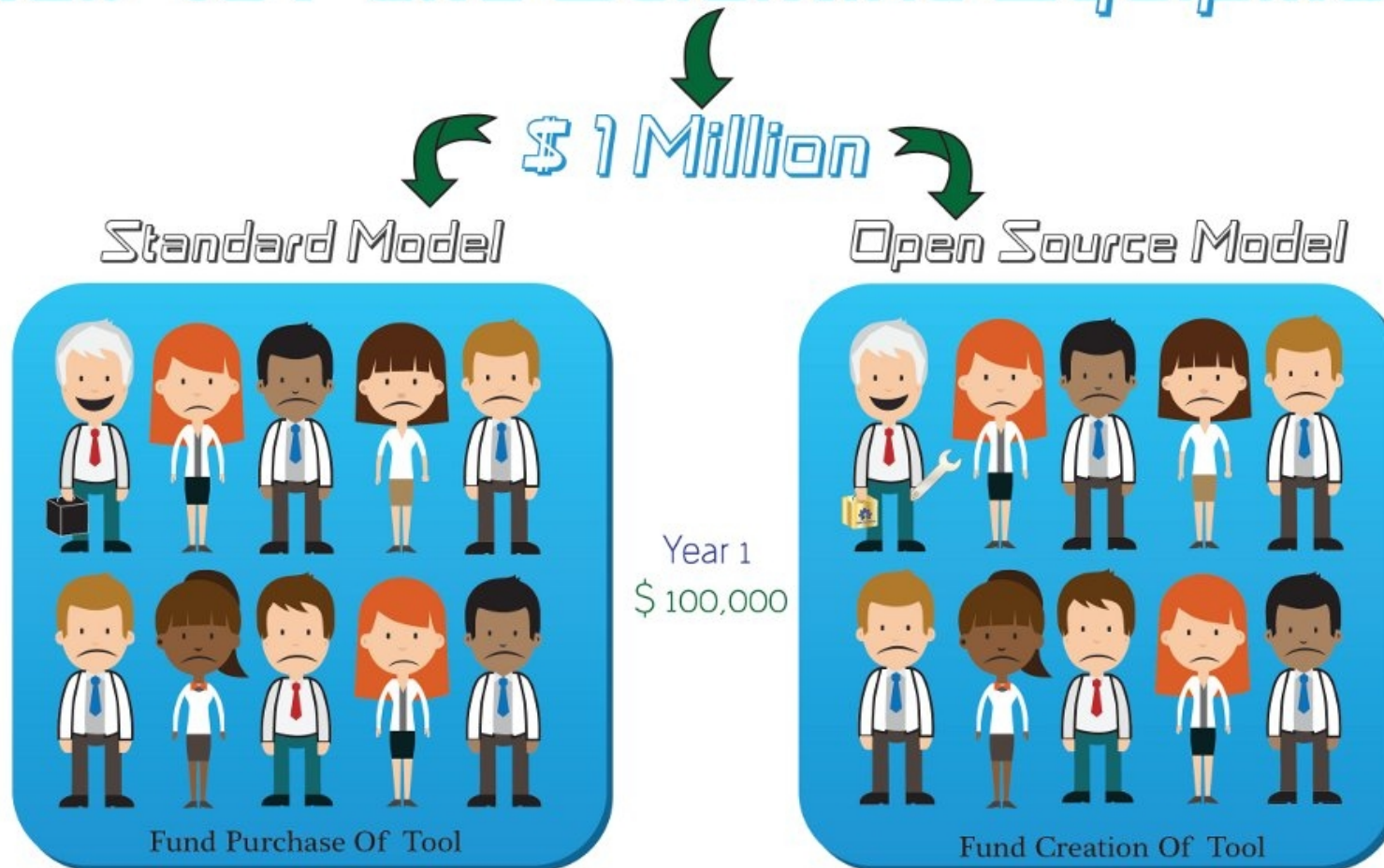


J.M.Pearce. Return on Investment for Open Source Hardware Development. *Science and Public Policy* 43(2),192-195 (2016).





# How to Fund Scientific Equipment



\* Only about 10% of NSF and NIH grants are funded

PEARCE



Black Box Proprietary  
Scientific Hardware  
No Control



Open Source  
Scientific Hardware  
Equivalent



Open Source  
Hardware  
Design



Open innovation  
results in better  
performance

\* Open source scientific hardware costs ~10% of proprietary hardware (Pearce, J.M. Open Source Lab, Elsevier, 2014).



# Proprietary



Year 2  
\$ 100,000



Year 3 to 10  
\$ 100,000  
per year

# FOSH





# Total

## Proprietary



Only 10 scientists funded for 10 tools, most out of date.

90% of scientists remain unfunded.

## Open Source Hardware (OSH)



91% of scientists funded, 91 state-of-the-art research tools, all open and easily upgrade-able for the cost of materials



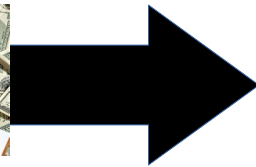
# **Recommendation 2**

**Direct fund FOSH  
development to  
maximize ROI**



# Recommendation 3

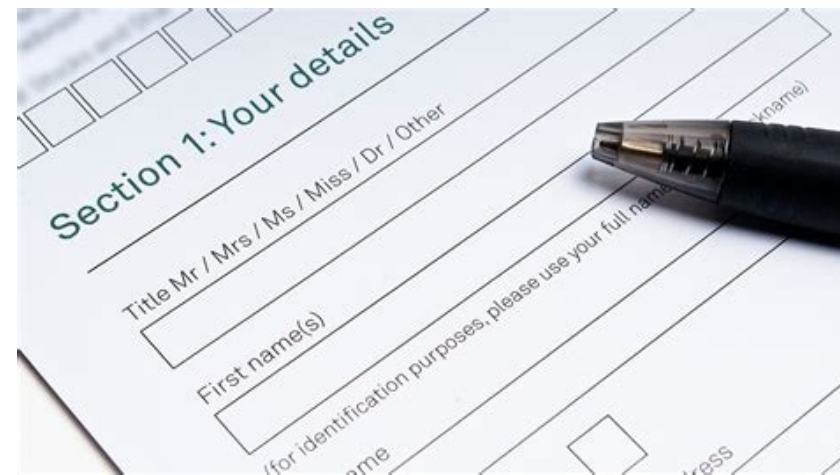
**Strategically  
purchase critical IP  
and open source it**



# Recommendation 4

## Purchasing Policy Preferences for FOSH for ALL funded projects

You want proprietary  
Equipment? Fine...  
Fill out this form!



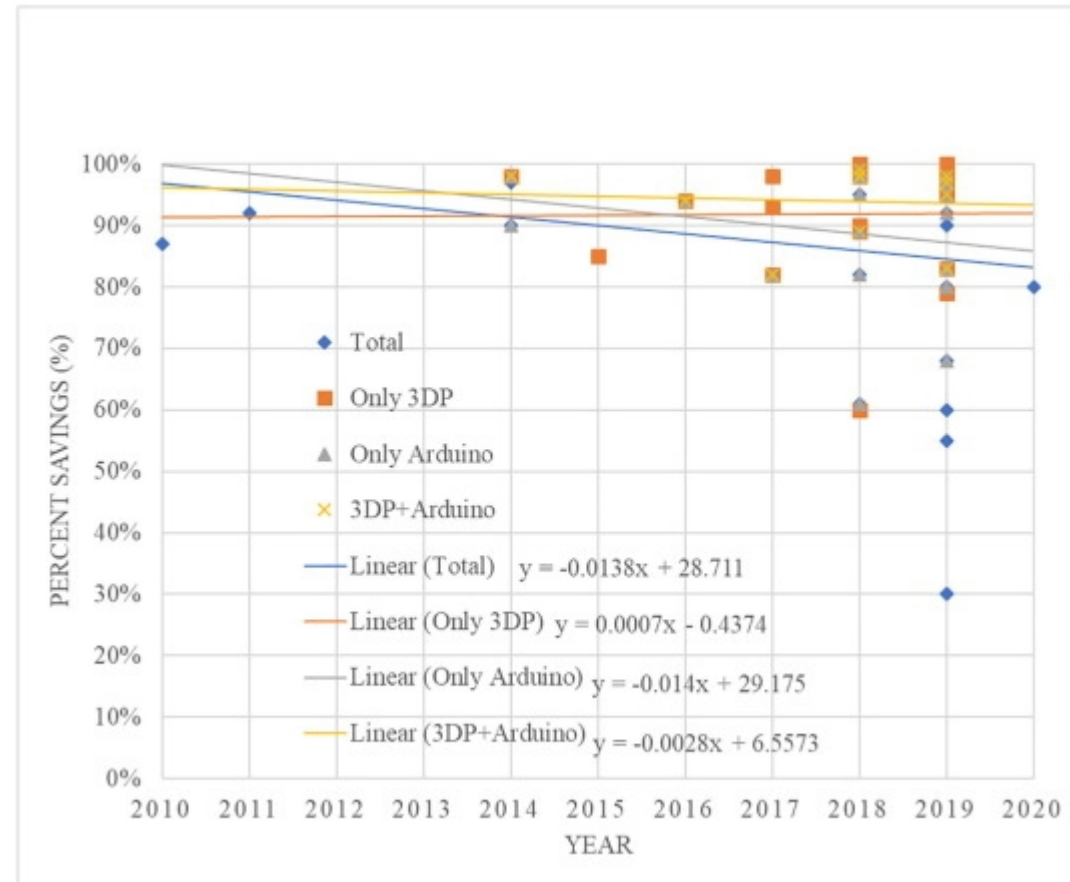
The image shows a close-up of a form titled "Section 1: Your details". The form has several fields: "Title Mr / Mrs / Ms / Miss / Dr / Other", "First name(s)", and a larger field for "Full name (s)". A black pen is resting on the form. The text "(for identification purposes, please use your full name)" is visible below the "First name(s)" field. The form is white with black text and lines.

# FOSH Still Saving!

*HardwareX/ PLOS* Toolkit Review: open source technologies provide economic savings of 87% compared to equivalent or lesser proprietary scientific tools.

Economic savings increased to 89% for those that used Arduino technology and even more to 92% for those that used RepRap-class 3-D printing.

**Combining both Arduino and 3-D printing the savings averaged 94% for FOSH over commercial equivalents.**



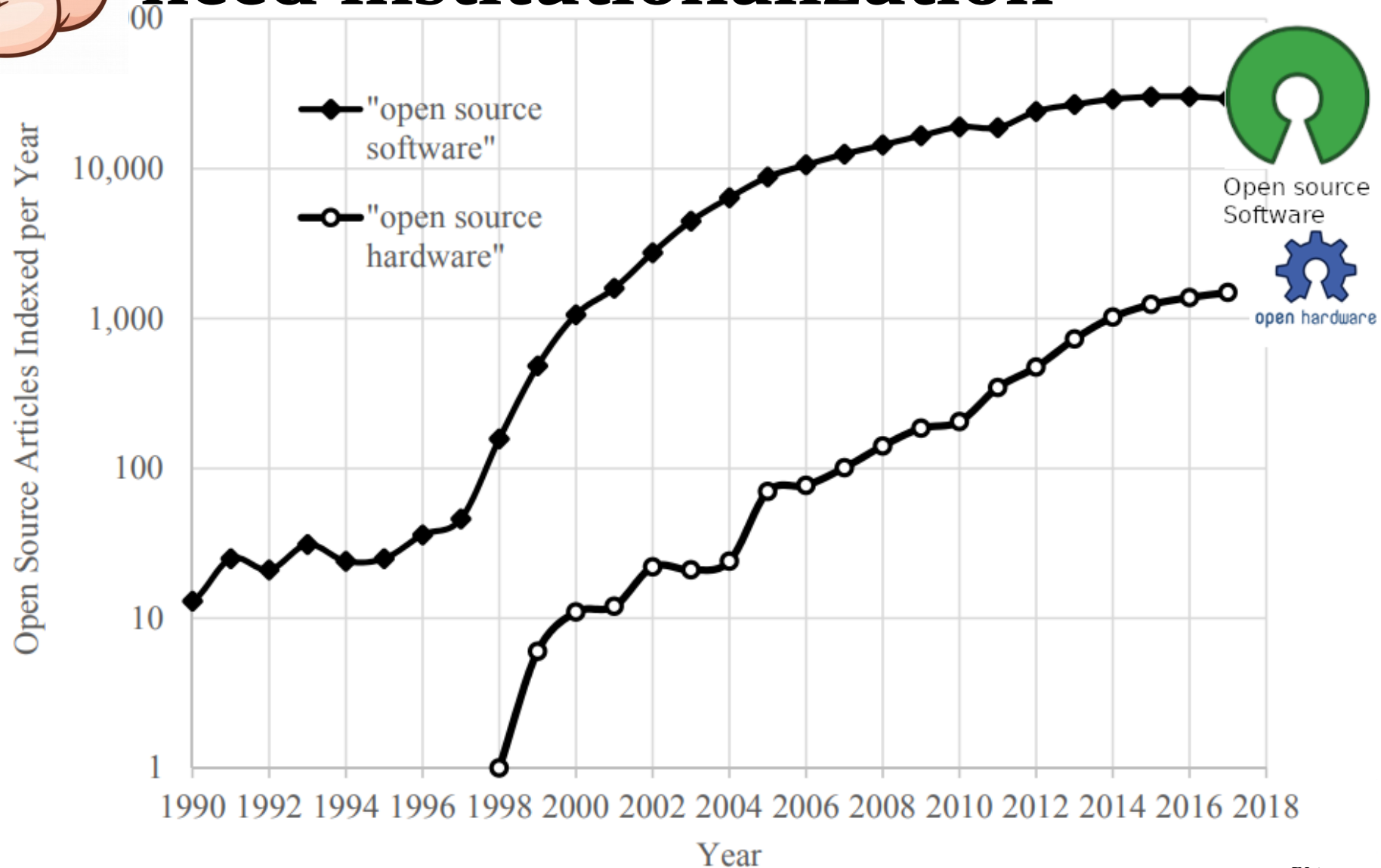
J.M.Pearce. Economic Savings for Scientific Free and Open Source Technology: A Review. *HardwareX* 8, 2020, e00139.  
<https://doi.org/10.1016/j.ohx.2020.e00139>





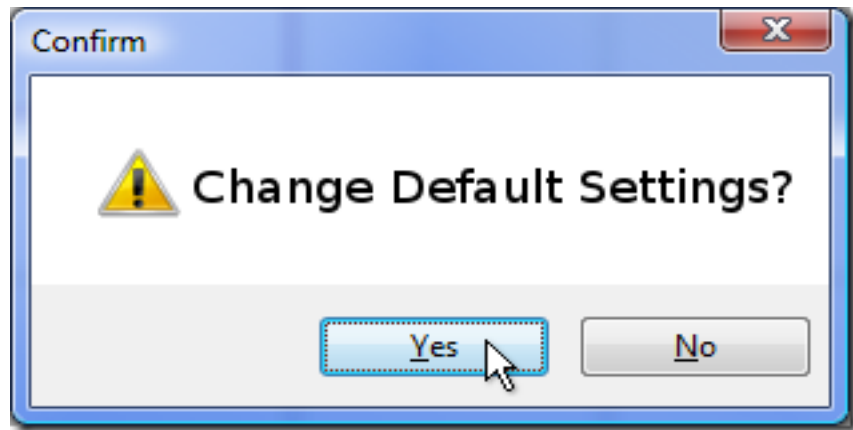


# We have barely started...but we need institutionalization



## Recommendation 5

Free on-line catalog of validated scientific FOSH (NIH → UN?)



Pearce, J.M. Impacts of Open Source Hardware in Science and Engineering. *National Academy of Engineering: The Bridge*. 2017.



# Recommendation 6

## Fund Open Source Endowed Chairs

What do we (faculty) really want?

- students
- small non-earmarked flexible money



An open source endowed professor would be required to:

1. **Put all intellectual property in the public domain or license all work with open source licenses.** This includes no patenting of research. Examples include licensing software with GNU General Public License or licensing hardware designs with the CERN Open Source License.
2. **Make all academic writing open access** either by publishing in open access journals or posting legal preprints in preprint repositories.







**Stop Funding Purchases of  
Proprietary Scientific Equipment!**  
**Instead fund FOSH development and  
BOMs for all scientists.**



**We Will All Stand on  
the Shoulders of Giants!**

pearce@mtu.edu

[www.appropedia.org/](http://www.appropedia.org/)



Appropedia.org/Pearce