

# Principles of Open Source Bioinstrument Design

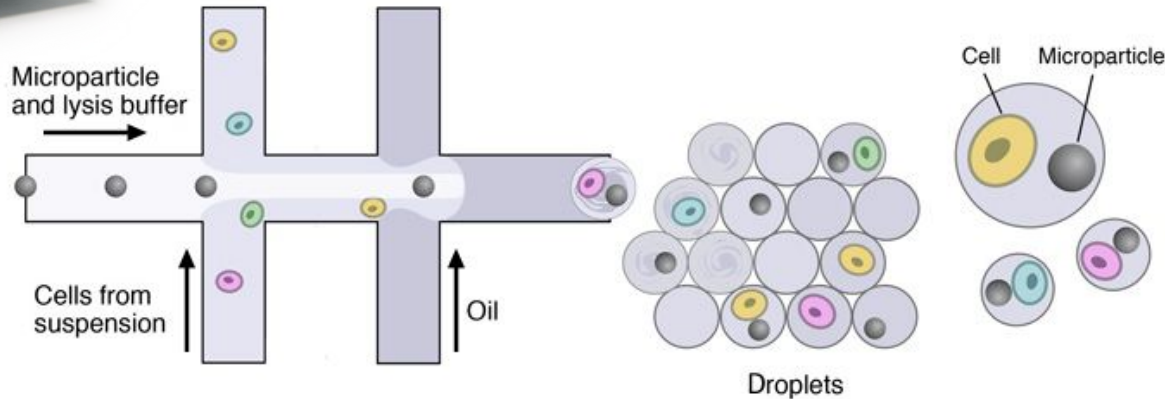
Anne Kil, Jase Gehring, Sina Booeshaghi  
10 October 2019

# Single-cell RNA Seq profiles thousands of cells

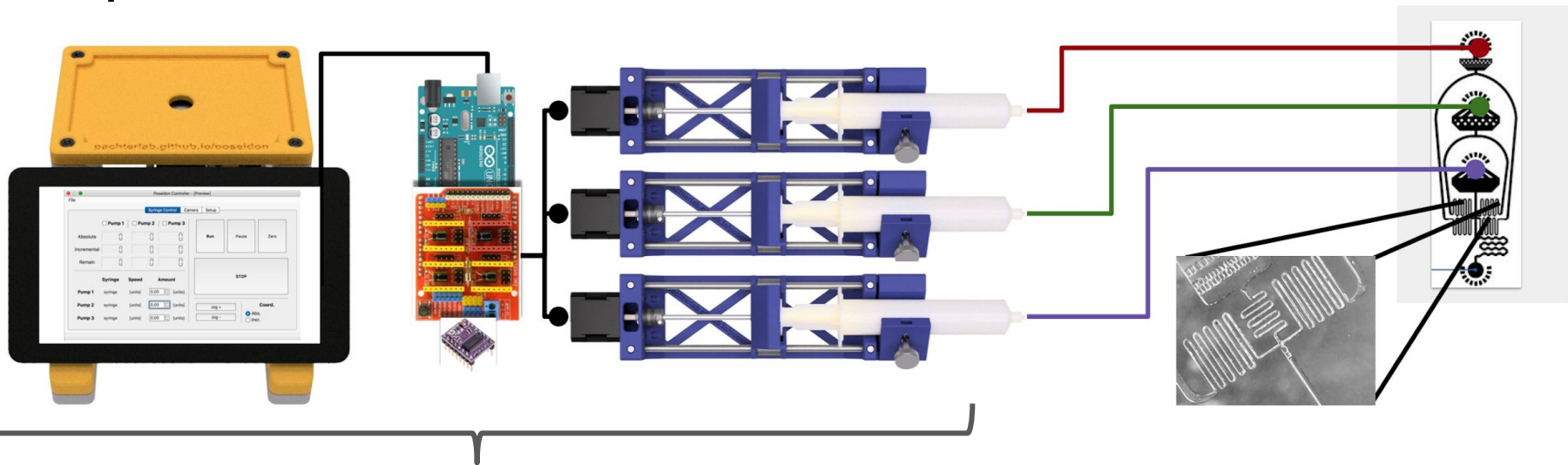


← Cost for a single 10x  
Genomics Machine \$75k  
Cost per run: \$1500

Cost for a DropSeq rig  
and Pumps \$10K  
Cost per run: \$600



# The problem: syringe pump/microscopes expensive, not hackable

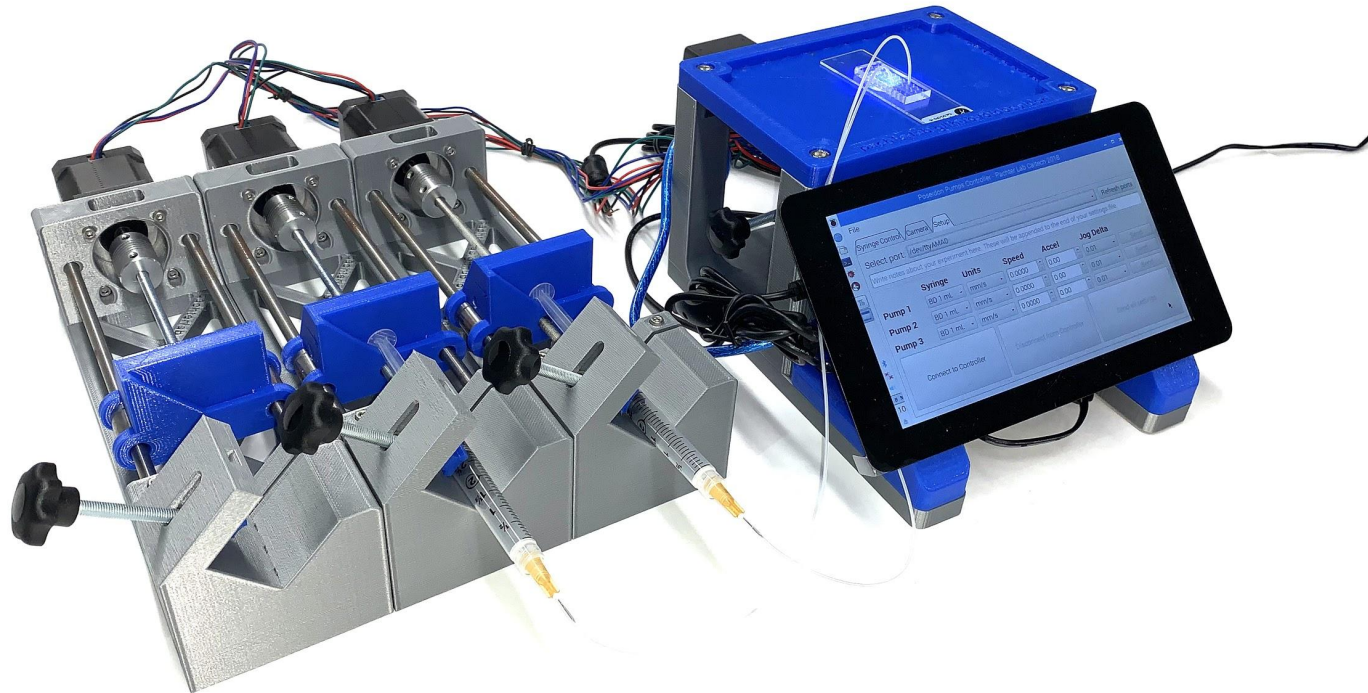


Poseidon Cost: ~\$310

Harvard Pumps Cost: ~\$5-10K



# The solution: poseidon an open source syringe pump and microscope system



# We followed 6 Principles of Bioinstrumentation to tackle the problem

1. Functionality (Follow functional requirements)
2. Simplicity (Avoid complicated solutions)
3. Modularity (Use standard components)
4. Robustness (The “idiot user” approach)
5. Benchmarking (Test and retest and retest)
6. Documentation (Videos, pictures, text)

**Recommendation:** print out a list like this and post it to your wall. It can help serve as a template for making design decisions.

# Functionality: Always start with a set of functional requirements

Specification	Description	Associated Value
Pump Size	Can be printed in one shot	Build Volume 8 x 8 x 10 in
Syringe Sizes	Adaptable to BD syringe	[1, 3, 5, 10, 20, 30, 60] mL
Desired Flow Rate	from DropSeq Protocol*	1,000-15,000 $\mu$ L/hr
Stepper Motor Driven	Run off of Arduino 12VDC	200 steps/rev w/ 32 $\mu$ step
Microscope	Magnification	Image microfluidic device
Cost	Total cost of the system + parts	<\$500

# With these requirements in mind, we selected the appropriate design tools

```
#!/bin/bash
# Requirements for the 3D printer

# Hardware
require python3
require git
require curl
require rsync
require nmap
require netcat
require socat
require socat

# Software
require python3
require git
require curl
require rsync
require nmap
require netcat
require socat

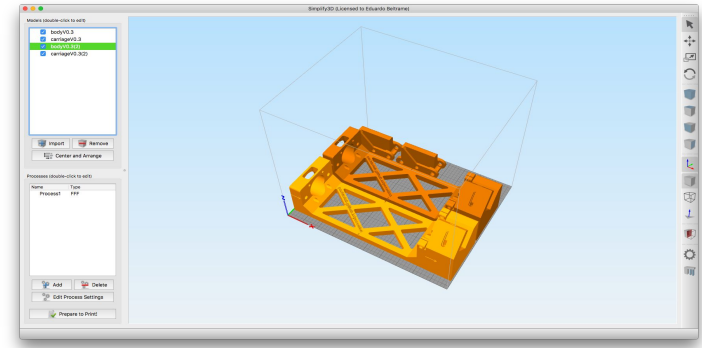
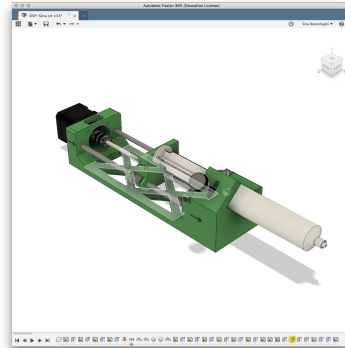
# System
require python3
require git
require curl
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```

```
#!/bin/bash
# Requirements for the 3D printer

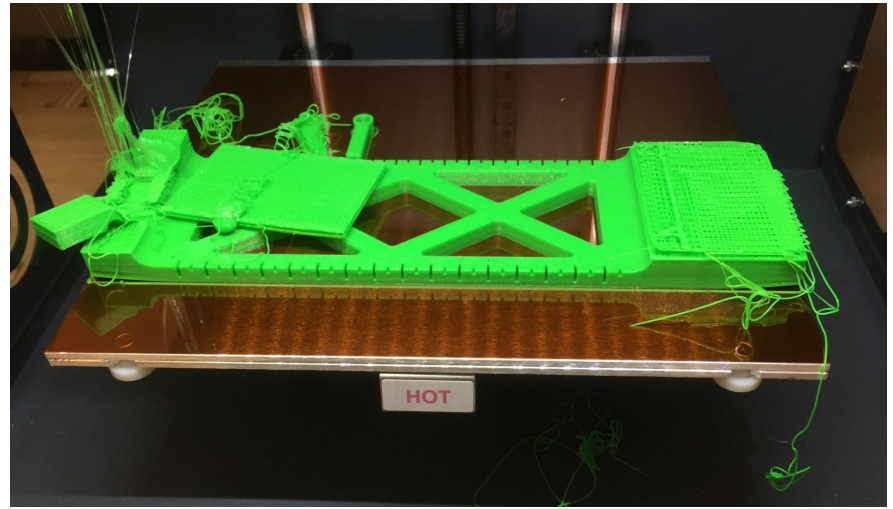
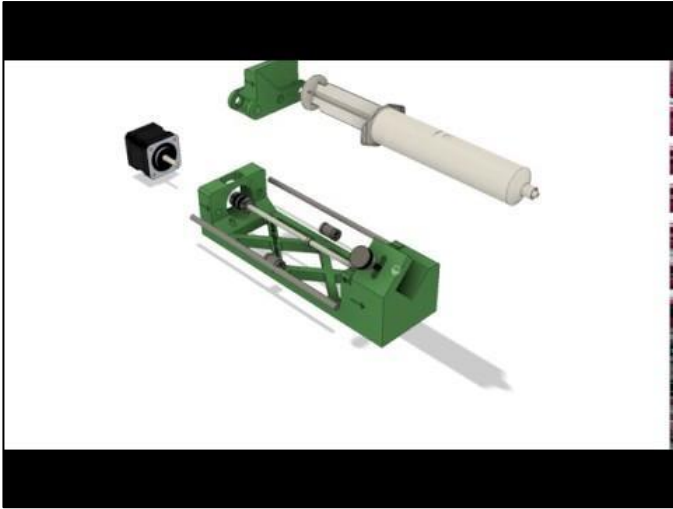
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```



Then we began designing and iterating..

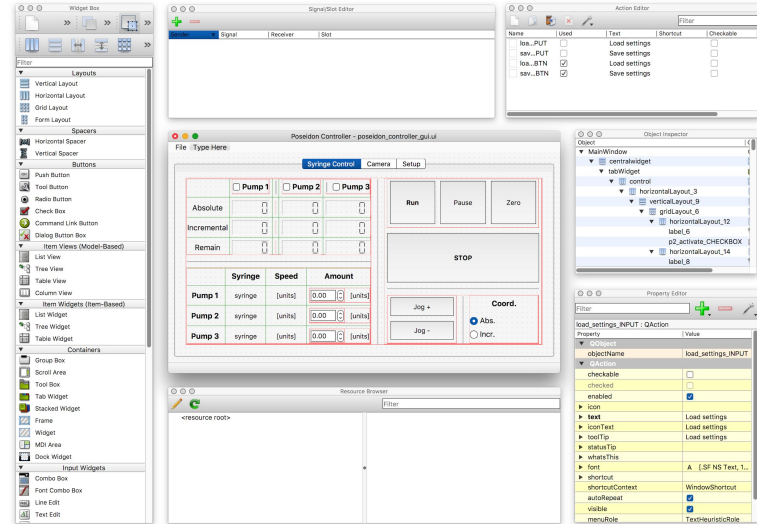
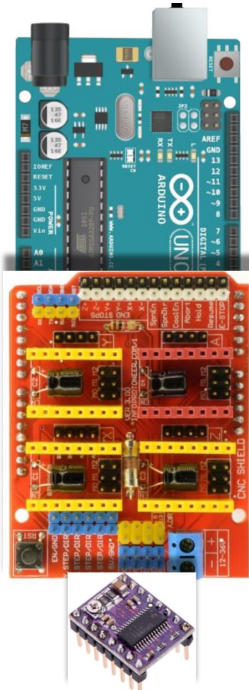




# Simplicity: We wanted the system to be simple enough to use but flexible enough to hack

## Hardware:

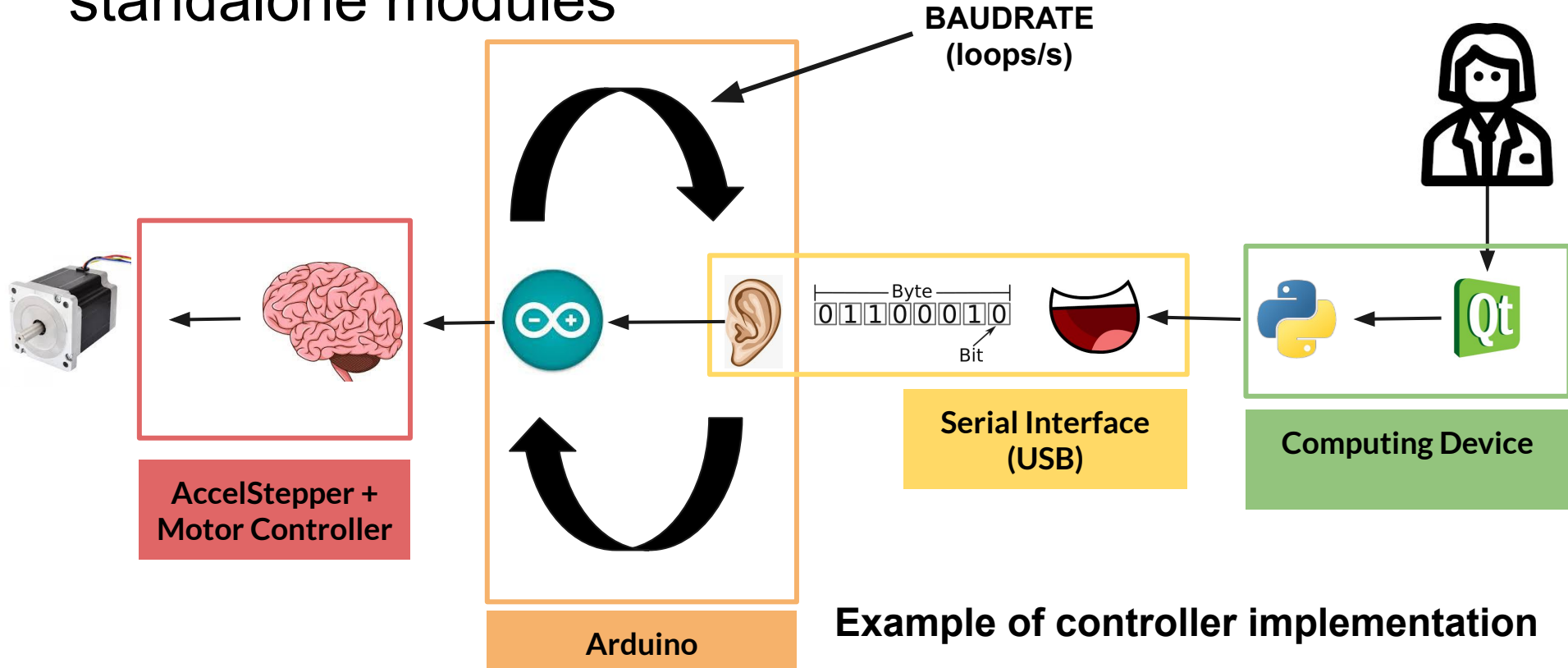
Plug and play parts, no soldering required



## Software:

Drag and drop GUI development, controls written in python

**Modularity:** System can be broken down into standalone modules



# Modularity: We used standard components

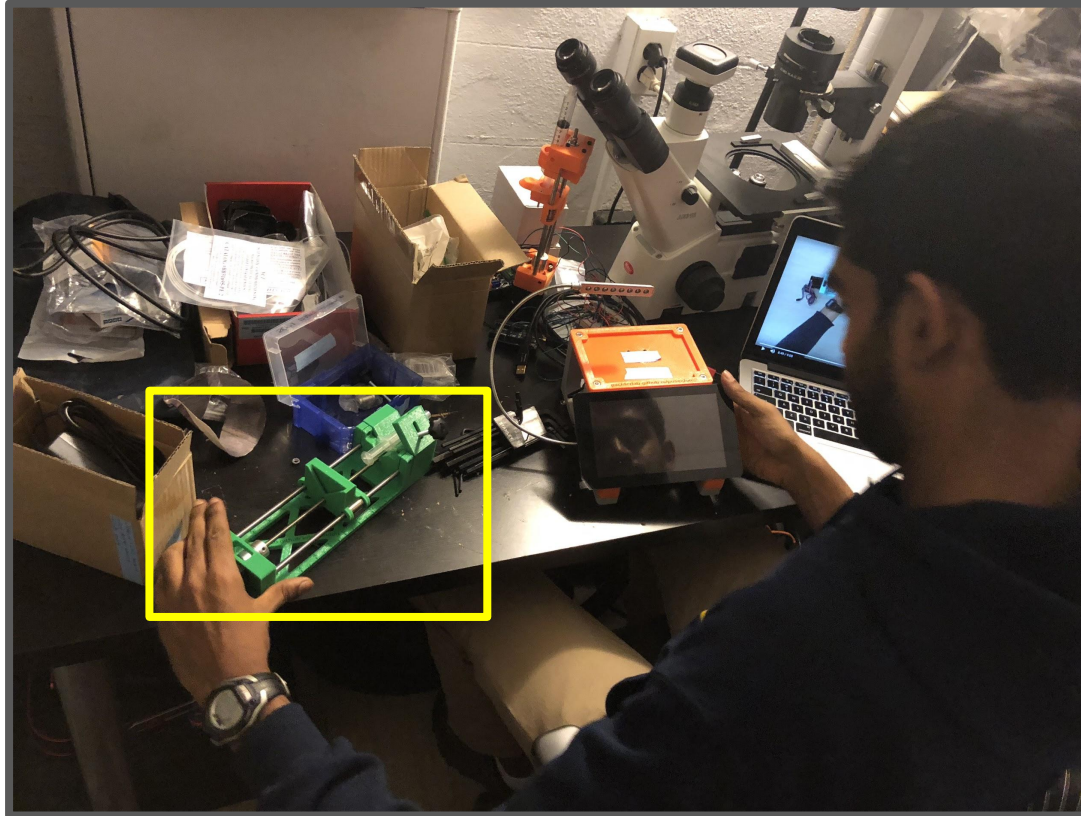
Syringe Pump Array		Cost per pump	31.445							
Total for 3 pumps		\$141.92								
Item Number	Item Description	Items per package	Items per Pump	Items per 3 pumps	Packages per 3 pumps	Cost per Package	Price per item	Cost per 3 pumps	Cost per pump	Supplier
1	Nema 17 Stepper Motor (Bipolar, 40mm, 59Ncm)	3	1	3	1	31.99	10.66333333	31.99	10.66333333	Amazon
2	5mm to 5mm Motor Shaft Coupling	10	1	3	1	22	2.2	22	2.2	Amazon
3	6mm Steel Rod (length 200mm, pack of 2)	2	2	6	3	6.24	3.12	18.72	6.24	Amazon
4	6mm Linear Bearing (pack of 12)	12	2	6	1	10.66	0.8883333333	10.66	1.776666667	Amazon
5	M5x0.8 Threaded Rod (length 170mm)	5	1	3	1	7.98	1.596	7.98	1.596	Amazon
6	M5x0.8 nut	50	2	6	1	6.23	0.1246	6.23	0.2492	Amazon
7	M3x0.5 socket head screws to mount motor (length 20	100	4	12	1	8.47	0.0847	8.47	0.3388	Amazon
8	M5 knob (hold syringe in place)	10	1	3	1	11.9	1.19	11.9	1.19	Amazon
9	12V power unit (end stripped to fit CNC shield power ir	1	0.3	1	1	9.89	9.89	9.89	2.967	Amazon
10	Arduino + CNC Shield Pack + DRV8825 (4)	1	0.3	1	1	14.08	14.08	14.08	4.224	Amazon
Microscope		Per Microscope	160.2768							
Microscope Total		\$169.01								
Item Number	Item Description	Items per package	Items per microscope	Packages per microscope	Cost per package	Price per item	Miscroscope cost			Supplier
1	Raspberry Pi Motherboard	1	1	1	34.99	34.99	34.99			Amazon
2	Raspberry Pi 7" touchscreen display	1	1	1	68.7	68.7	68.7			Amazon
3	Raspberry Pi Power Suppy (5v 1.5A DC)	1	1	1	9.99	9.99	9.99			Amazon
4	16gb MicroSD card (comes with adapter)	1	1	1	7.17	7.17	7.17			Amazon
5	Keyboard + Mouse Bundle (wired)	1	1	1	14.44	14.44	14.44			Amazon
6	M5x0.8 Socket Head Screw (length 14mm)	15	8	1	7.5	0.5	4			Amazon
7	M5x0.8 nuts	50	8	1	6.23	0.1246	0.9968			Amazon
8	USB Camera	1	1	1	19.99	19.99	19.99			Amazon
Project Total		\$310.93								

# Robustness: Employing the idiot user approach



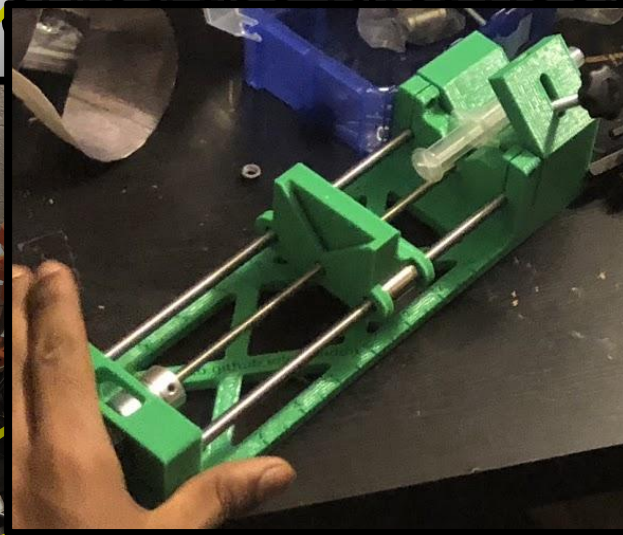
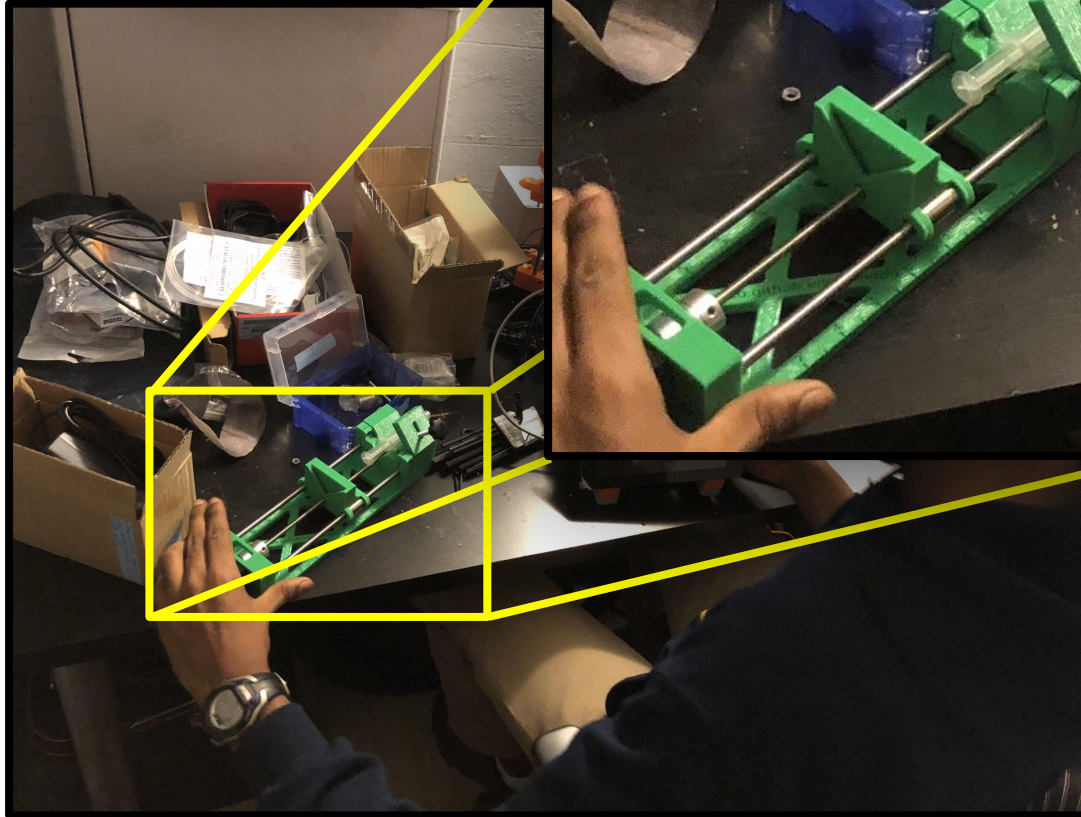
**Notice something wrong with the device?**

# Robustness: Employing the idiot user approach



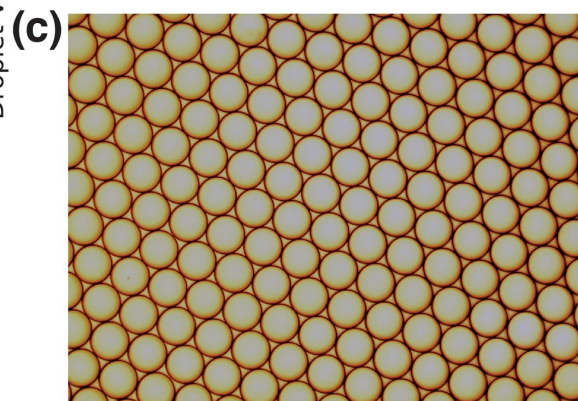
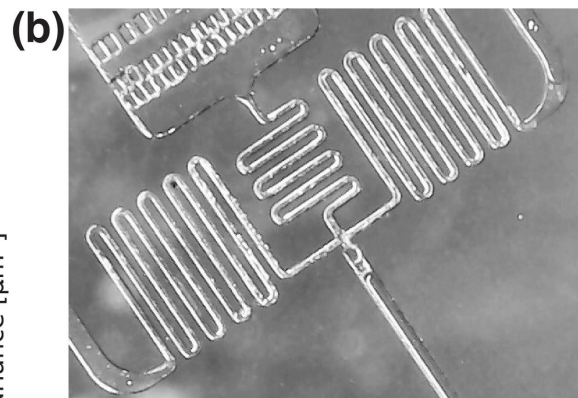
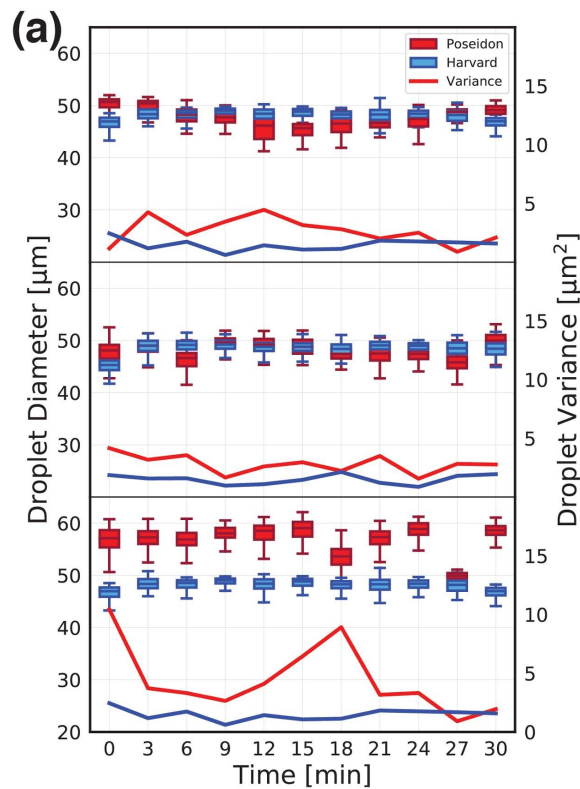
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**Robustness: Emphasizing the initial approach**

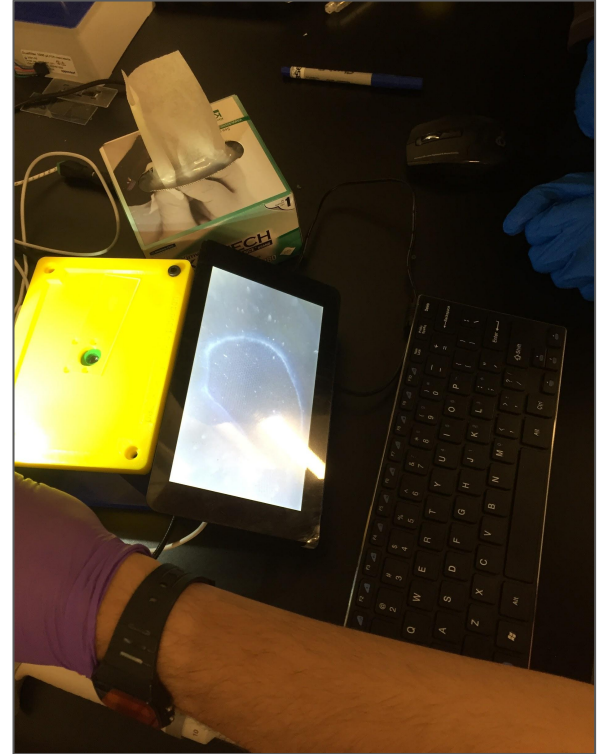
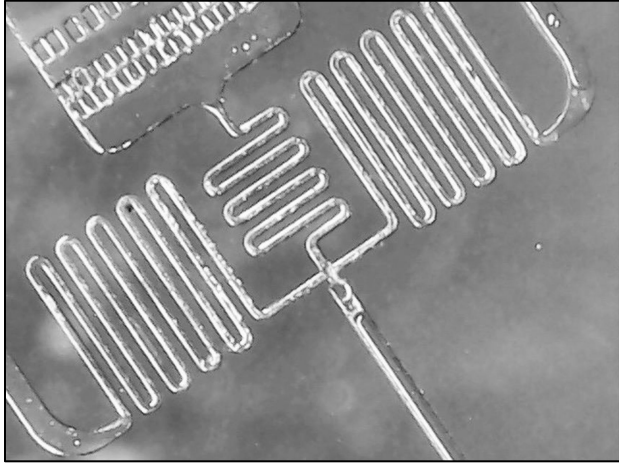


**Notice something wrong with the device?**

# Benchmarking: Test and retest and retest

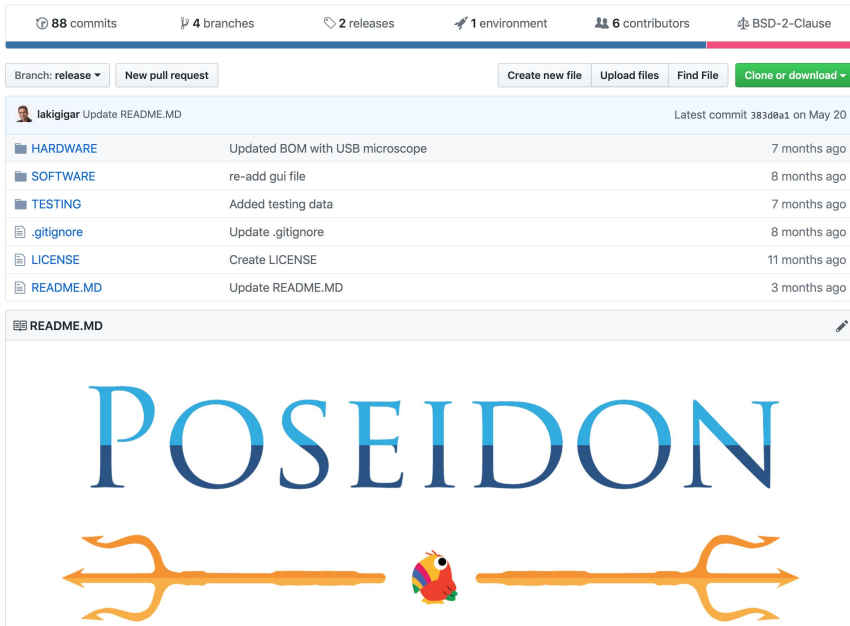


# Benchmarking: Test and retest and retest





# Documentation: The most important (and hardest) part of designing



88 commits 4 branches 2 releases 1 environment 6 contributors BSD-2-Clause


Branch: release New pull request Create new file Upload files Find File Clone or download

lakigigar Update README.MD Latest commit 383d8a1 on May 20

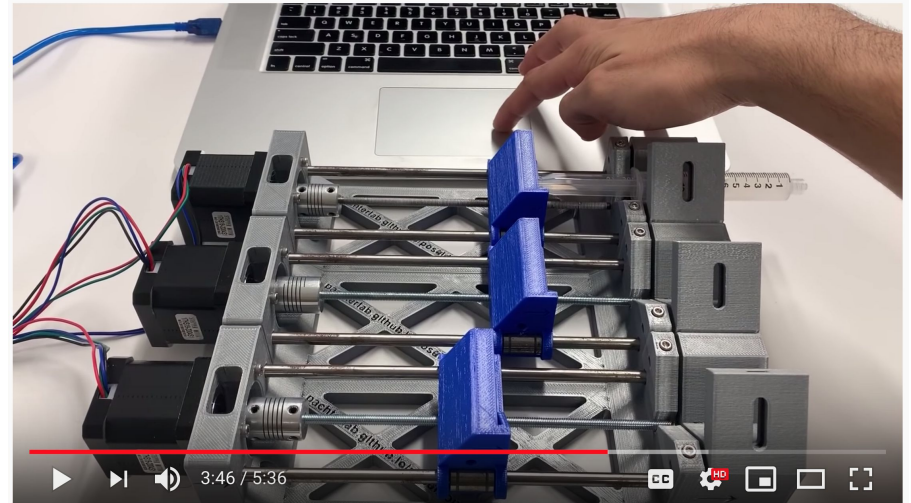
Category	Commit Message	Time Ago
HARDWARE	Updated BOM with USB microscope	7 months ago
SOFTWARE	re-add gui file	8 months ago
TESTING	Added testing data	7 months ago
.gitignore	Update .gitignore	8 months ago
LICENSE	Create LICENSE	11 months ago
README.MD	Update README.MD	3 months ago

README.MD

# POSEIDON



The screenshot shows a GitHub repository for a project named 'POSEIDON'. At the top, it displays repository statistics: 88 commits, 4 branches, 2 releases, 1 environment, 6 contributors, and a BSD-2-Clause license. Below this, there are buttons for 'Branch: release', 'New pull request', 'Create new file', 'Upload files', 'Find File', and 'Clone or download'. A commit history table follows, listing updates to README.MD, HARDWARE (BOM), SOFTWARE (gui file), TESTING (data), .gitignore, LICENSE, and README.MD. The bottom part of the screenshot shows the README.MD file, which features the word 'POSEIDON' in large blue letters and a logo consisting of a golden trident with a small colorful fish-like character in the center.



Running poseidon for the first time

3,405 views

12 0 SHARE SAVE ...

*“Any code written by oneself six or more months ago should be considered someone else’s code”*

# Recap: Principles are good, only if you follow them

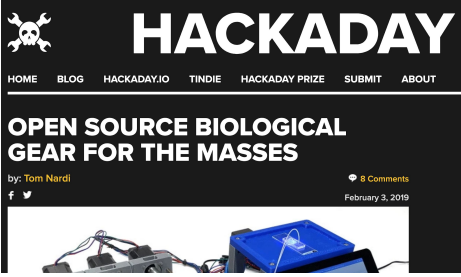
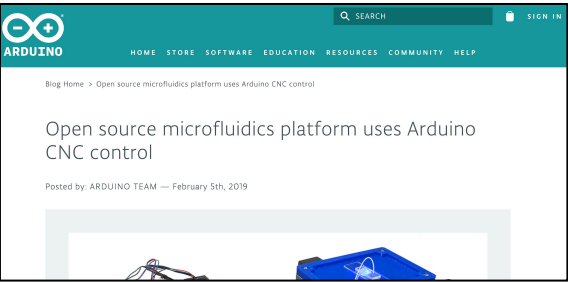
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# Marketing Efforts.

Abstract	Full-text HTML	PDF
3,371	195	2,832

- Blogged by 1
- Tweeted by 70
- 13 readers on Mendeley



Unwatch 14
Unstar 64
Fork 18

Hacker News new | comments | ask | show | jobs | submit login

- Michael Dell Gets \$12B Richer with Break from Public Eye (bloomberg.com) 57 points by walterbell 3 hours ago | hide | 38 comments
- MIDI 2.0 Prototyping announced (midi.org) 252 points by kristiandupont 8 hours ago | hide | 100 comments
- VLC developers refuse to consider updates over HTTPS (videolan.org) 11 points by GordonS 31 minutes ago | hide | 3 comments
- EU Cancels 'Final' Negotiations on EU Copyright Directive (techdirt.com) 200 points by rwmj 4 hours ago | hide | 38 comments
- Tularosa Study: Experimental Quantify the Effectiveness of Cyber Deception [pdf] (hawaii.edu) 13 points by adulau 3 hours ago | hide | discuss
- Open sourcing bioinstruments (liorpachter.wordpress.com) 24 points by homarp 4 hours ago | hide | 1 comment**
- Iridium Completes Constellation Replacement (flyingmag.com) 17 points by prostoaalex 3 hours ago | hide | 4 comments
- Remotely compromise devices by using bugs in Marvell Avastar Wi-Fi (embedi.org) 86 points by skeetmtp 8 hours ago | hide | 32 comments
- Ask HN: Is there any money in website

Lior Pachter @liorpachter 5 days

scope Station Syringe Pump

Open sourcing bioinstruments liorpachter.wordpress.com/2019/01/18/ope... pic.twitter.com/9dg8S5h5zf

via WordPress.com

86 218 14291

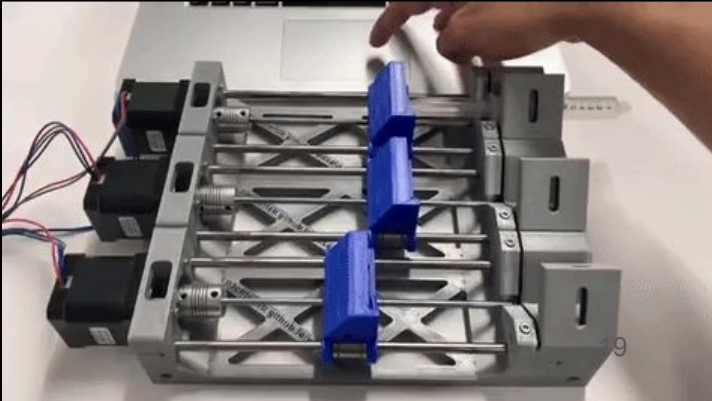
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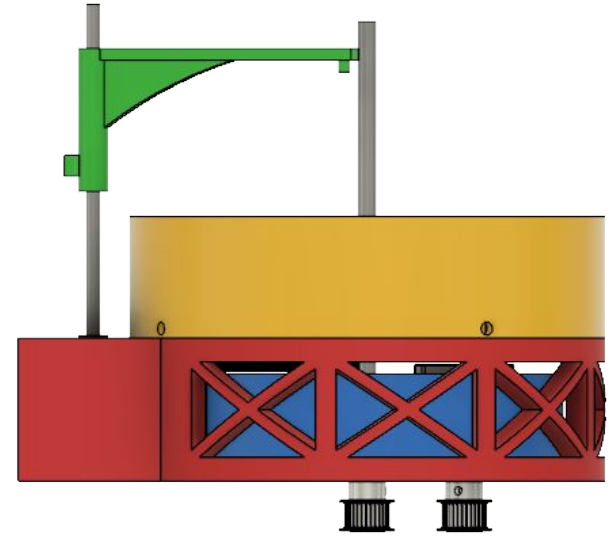
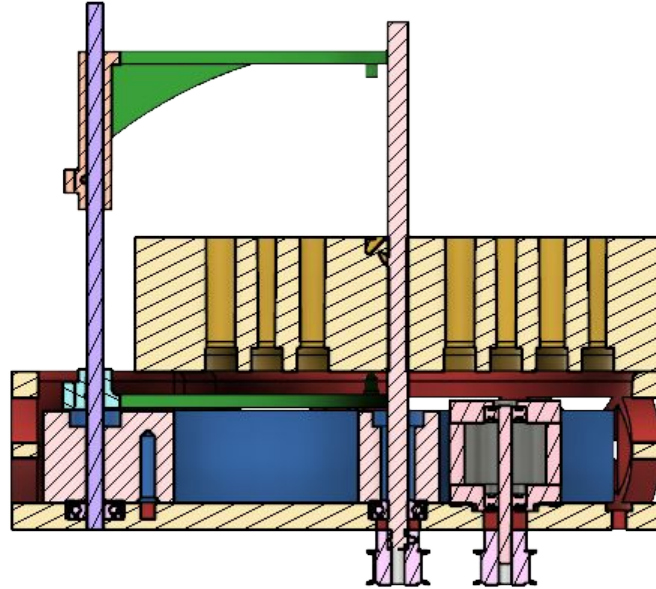
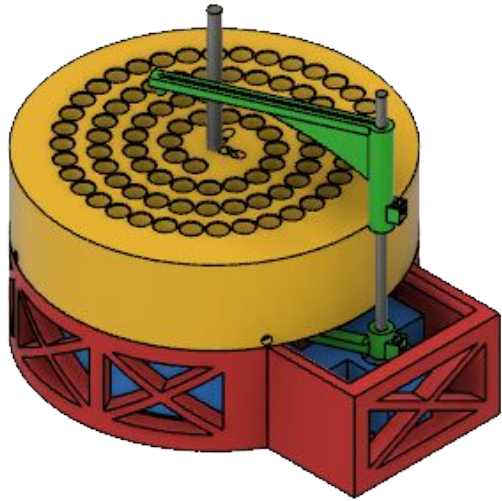
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Open-sourcing bioinstruments (liorpachter.wordpress.com)

77 points by homarp 4 days ago | flag | hide | past | web | un-favorite | 33 comments



# Future: Applying these principles to other projects



Automated fraction collector, work done with Anne Kil (Pachter Lab SURF '19)

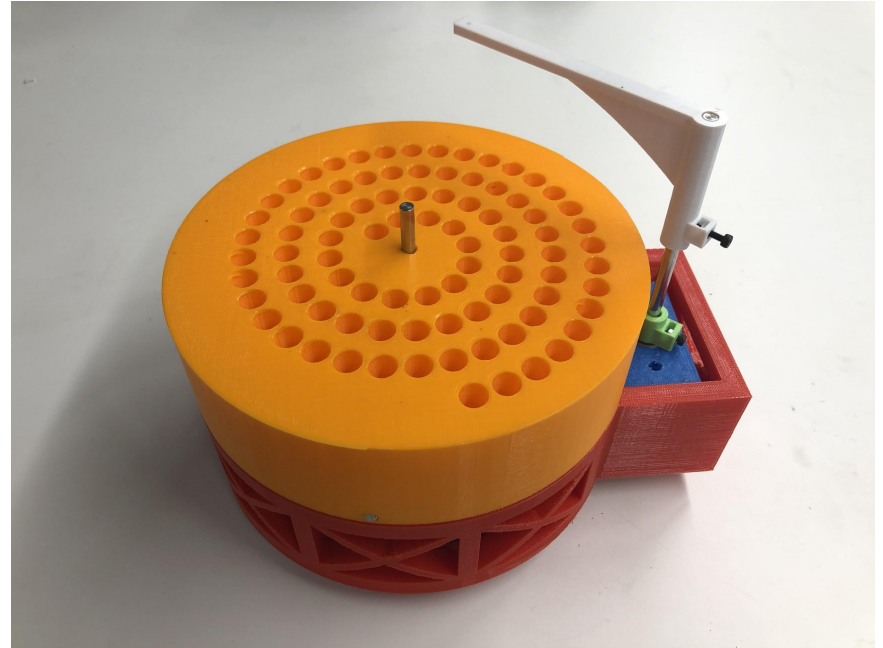
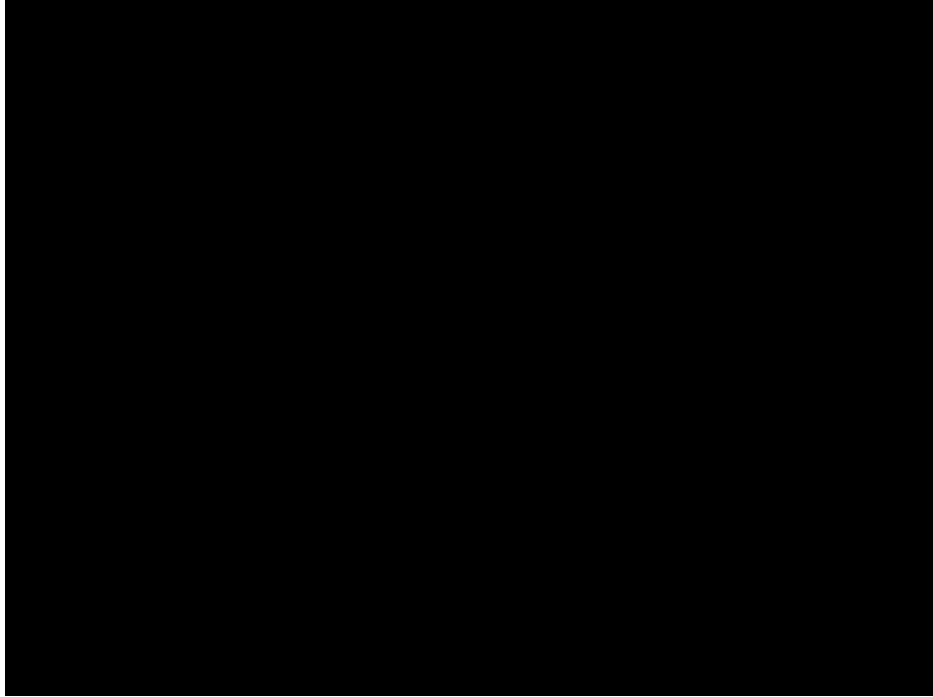
# What is a fraction collector?

Model	# of tubes	Price (USD)
GE Frac30	30	1,703
Eldex UFC	135 or 160	3,707
Spectrum Spectra FC	174	4,583
Buchi C-660	12, 30, or 60	12,141
Open-source	Customizable	<100

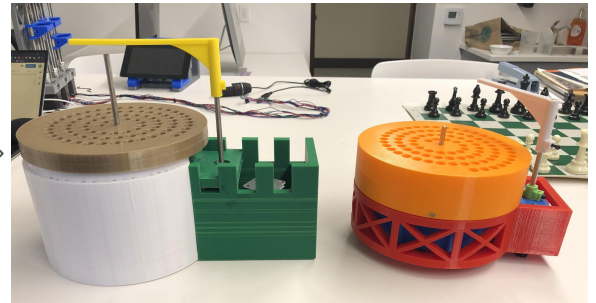
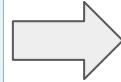
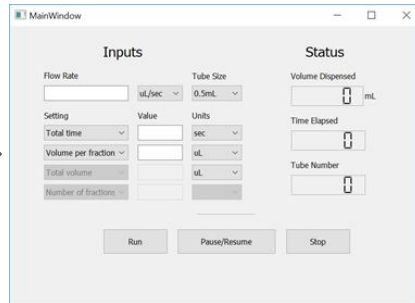
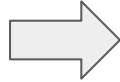
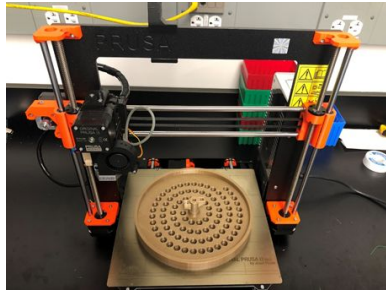
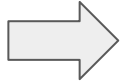
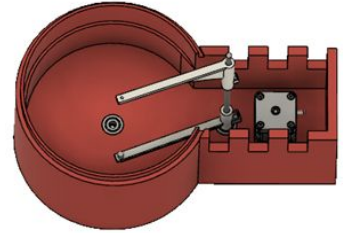
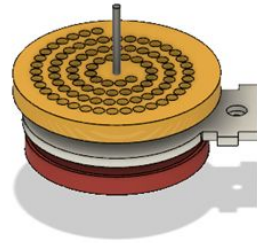
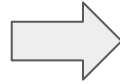
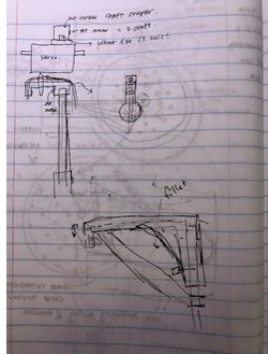
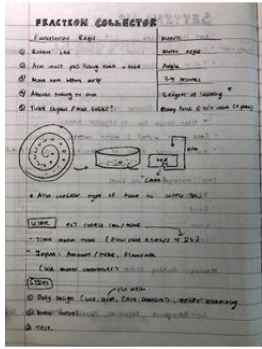


GE Healthcare's Frac 920, \$2,400 for used

# The open-source fraction collector, colosseum



# How did we make the colosseum fraction collector?



# Difficulties and Challenges

## Technical difficulties:

- Streaming commands to the Arduino
- Figuring out 3D printer tolerances
- 3D printer problems

## Design challenges:

- Simplifying design
- Benchmarking commercial devices



# A many thanks to those who helped on the project



Professor Lior  
Pachter



Jase Gehring



Eduardo Da Veiga  
Beltrame



Dylan Bannon

*\*Not pictured: Anne Kil*

**Project website: <https://pachterlab.github.io/poseidon/hardware>**

# If you like these kinds projects then reach out to us!

We can work together to develop all sorts of novel bioinstruments. Our goal is to produce open, reliable, and modifiable bioinstruments for academic, medical, and research applications.

Examples of possible projects:

1. Fast Pressure Liquid Chromatography (Protein purification)
2. Vacuum driven microfluidics
3. Automated cell culture

Or just stop by our offices in the basement of Kerckhoff to check out our lab.

**Contact: Sina Boeshaghi ([abooesha@caltech.edu](mailto:abooesha@caltech.edu))**