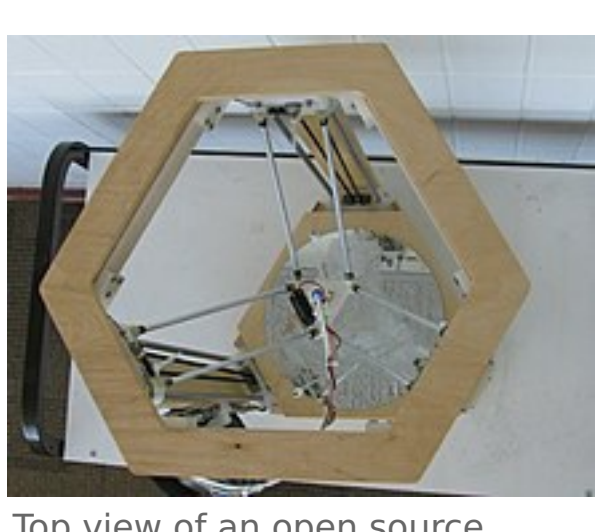
Open Source 3-D Printing

Open Source 3-D Printing (OS3DP)

Note to Professors/Instructors



Top view of an open source RepRap MOST Delta-style 3-D printer called the Athena (more information (http://www.appropedia.org/Athena_Build_Overview)).

This is an undergraduate/graduate engineering course originally developed and taught by Dr. Joshua M. Pearce, to teach students everything they need to know about open source 3-D printing in the RepRap tradition. When taught at Michigan Tech (http://www.appropedia.org/MY4777) there is a $500 course fee for this course. This fee is used to purchase a MOST Delta RepRap 2 (http://www.appropedia.org/AthenaII) kit for students to build in the course, use in the course and then keep afterwards. Other universities that have adopted a variant of this course have either made a 3-D printer lab the students could use for the course, loaned out 3-D printers to students (e.g. Lulzbot Taz (https://www.lulzbot.com/) commercial RepRaps) or had students build a JellyBox (https://www.imade3d.com/jellybox/) RepRap that students assemble with zip ties and the disassemble for the next class. It is better if the students can build and hack their own systems, but that may be economically prohibitive in which the other methods are good substitutes. The difference between the undergraduate and graduate versions of the course is that the graduate students must do everything the undergraduates do, but also make a significant improvement on the RepRap printers and publish their mods.

Educators - you are free to take all or any part of this course and adapt it at your school including the videos. If you want access to the slides please email pearce@mtu.edu

The course is built around a selection of progressively more challenging exercises use to teach students OpenSCAD, FreeCAD and Blender so they can solve just about any 3-D printing design challenges. Here are the projects and a brief description.

- Open Source 3-D Printing/Rock wall project - teaches the basics of OpenSCAD and is an easy first assigned print to ensure the students can use the 3-D printers
- Open Source 3-D Printing/Customizer project - teaches a more advanced version of OpenSCAD to make it easy for novices to adapt the student's designs
- Open Source 3-D Printing/Viking mashup project - teaches how to take an open source design from the web and make a challenging adaptation to it - e.g. how to revise and mod others' designs
- Open Source 3-D Printing/Adaptive Aid - this is a virtual service learning project meant to demonstrate to students how open source sharing can help real people
- Open Source 3-D Printing/OSH Science project -this is a service learning project and a mini-version of the course 3D Printing of Open Source Hardware for Science that helps students get to know research problems at their schools and how to design for high tech environments
- Open Source 3-D Printing/OSAT projects - this is a virtual service learning project meant to demonstrate to students how open source sharing can help real people in resource constrained contexts
- Open Source 3-D Printing/Big Money Project - this is the final project for the undergrads - helping them to combine everything they learned to demonstrate how they can create high value products using a low cost open source RepRap 3-D printer

Open Source 3-D Printing

Why Take This Course?

Why 3-D Printing? A recent report from data company Wanted Analytics found that in one month 35 percent of engineering job listings (https://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/8431/Wanted-Analytics-Demand-For-3D-Printing-Skills-Soars.aspx) from a variety of fields, including biomedical, software, and transportation industries, required applicants familiar with 3-D printing.[1] (http://theinstitute.ieee.org/career-and-education/career-guidance/thirtyfive-percent-of-engineering-jobs-now-require-3d-printing-skills) Forbes explains why 3D printing is such a big deal (http://www.forbes.com/sites/louiscolumbus/2015/03/31/2015-roundup-of-3d-printing-market-forecasts-and-estimates).

Why open source? You will make more money, because OS is more valuable. Recent analysis shows that jobs with the keywords "Microsoft Windows" have an average salary of $64,000, while jobs with the keyword "Linux" have an average salary of $99,000. [2] (http://www.indeed.com/salary?q1=linux&q2=microsoft+windows)

Course Description

This course provides an introduction to distributed additive manufacturing using open-source 3-D printing. First this course will provide an overview of open-source hardware and technological development in theory and practice. Both the use of software and user communities will be highlighted and demonstrated. Next, the course will detail the design, use and maintenance of the open-source electronics behind the development of self-replicating rapid prototypers. Then the technological evolution of the open-source 3-D printing technology will be covered with a focus on developing innovation for improved performance and materials selection. **Each student will build a customized RepRap** and the course will cover hardware, firmware, slicing and printer controller software for operating and maintaining the device. Finally the material properties, applications and ramifications of RepRap technology will be discussed.

The course is meant for advanced undergraduate and graduate students in engineering or science. Graduate students are expected to complete all coursework assigned to the undergraduates and an in depth project.

Required Course Material

Textbook: J.M. Pearce, *The Open-Source Lab (http://www.appropedia.org/Open-source_Lab)* (Elsevier,2014). Other reading will be handouts in class, on-line reading, and emailed pdfs. See hyperlinks in schedule.

An open source 3-D printer kit of the RepRap type available from many commercial vendors.

Free and open source software needed:

- OpenSCAD (http://www.openscad.org/),
- FreeCAD (https://www.freecadweb.org/),
- Blender (https://www.blender.org/),
- Franklin (http://www.appropedia.org/Franklin:MOST)
- Lulzbot Edition Cura (https://www.lulzbot.com/cura).

Laptop computer to be brought to class.

Course Organization

This course will be run as an intense seminar meeting as a group. Students will be expected to read the course material before class and actively participate in discussions. The majority of class time will be spent on projects in a flipped class format. Each student will be responsible for building a RepRap 3-D printer to use to complete the projects. Students will be responsible for giving short presentations on their projects on each sub-topic in front of the class at the end of the semester.

Graduate students will take the same lecture and projects as the undergraduates, however, they will also be expected to complete a significant improvement to the RepRap design by the end of the semester. They will demonstrate their mods for the class.

Learning Objectives

- Learn the fundamentals of additive manufacturing (AM) and 3-D printing with polymers, along with those for emerging materials (e.g., metals, ceramics, flexible materials, nanocomposites, biomaterials) and complex architectures.
- Learn the fundamentals of free and open source hardware (FOSH) design, licensing, and culture.
- Understand and demonstrate the fabrication, maintenance, trouble shooting and operation of self-replicating rapid prototype (RepRap) 3-D printers.
- Understand operating principles, capabilities, and limitations of fused filament fabrication (FFF)-based 3-D printing.
- Understand the principles of "Design for 3-D printing" and compare and contrast additive processes with conventional manufacturing in terms of rate, quality, cost, environmental impact, social control and flexibility.
- Gain hands-on experience with RepRap 3-D printers; use these machines to fabricate example parts of increasing complexity, post-process the parts, and study the results.
- Become familiar with the complete workflow of open source AM, including computational design tools, firmware, software, file formats, toolpath generation, and characterization.
- Understand how to make a new part and alter an existing part for RepRap 3-D printing for custom applications.
- Study applications of distributed manufacturing using 3-D printing including consumer products, scientific equipment, and appropriate technology.
- Place open source 3-D printing in the context of the evolving distributed manufacturing infrastructure.

Grading

Grades will be based on the following:

RepRap build	**50**
Appropedia user page, 4x mini projects	**50**
Arthritis Aide Project	**200**
Science Equipment Project	**250**
OSAT Project	**250**
Big Money Project or Science Equipment Advanced	**200**
Total Points	**1000**

- Grad students must also complete an improvement to the RepRap OR a 3-D printed **automated** Scientific Apparatus worth 1000 points and be graded out of 2000.

Late Assignments

Deduct 10% per day, up to 5 working days, then 0 grade. Only exception is for documented illness. Missed projects are penalized by the negative square of the percent total.

Course Policies

Appropriate behavior, attendance, participation and collaboration with your peers on group assignments is expected. Collaboration/Plagiarism Rules: Collaboration is encouraged on the group project but the individual project must be completed alone.

Course Schedule

OSL= *Open-Source Lab* textbook
All course videos are housed on the open science framework - you can watch them there or download them.

Class# and video	Class description	Assignment
Video 1 (https://osf.io/85mr2/)	Intro to class, build, big money, grad and mod, assigned	Syllabus, Schedule, M0.1
Video 2 (https://osf.io/pwt5j/)	Get kits - Start Building Your 3D Printer!	**Bring bags/boxes for large part and a sealed container for small parts**. Safety, Start building, M0.2
Video 3 (https://osf.io/e5xs8/)	RepRap software chain	M0.3,M0.4
Video 4 (https://osf.io/3bazs/)	OSH definitions, development, business	M1.1
Video 5 (https://osf.io/tw4ep/)	OS licenses, legal discussion	M1.2
Video 6 (https://osf.io/7j8tq/)	RepRap show and tell (monster build) (lecture on RepRap background)	**RepRap built**, **BRING IT TO CLASS**
Video 7 (https://osf.io/x5gzc/)	RepRap community, Printing tricks, Intro to wiki-Appropedia (http://www.appropedia.org/)	M2.1-3, Create and populate Appropedia user page
Video 8 (https://osf.io/frg3c/)	OpenSCAD Tutorial part 1/ in class micro project Rock wall project	M3.3, M3.4,
Video 9 (https://osf.io/uv9ws/)	OpenSCAD Tutorial part 2/ in class micro project - parametric script - **Solve Everyone's Problems** Customizer project	M3.3, M3.4,
Video 10 (https://osf.io/h4ak2/)	FreeCAD Tutorial/in class micro project lens cover (http://www.thingiverse.com/thing:1782956)	M3.5
Video 11 (https://osf.io/tvyef/)	Viking Mashup Project Blender Tutorial/in class micro project lamp shade (http://www.thingiverse.com/thing:1781307)	M3.2, M0.4
xx	Microproject show and tell	**Bring microprojects printed**
Video 12 (https://osf.io/k4sze/)	Mechanical properties of 3-D printed parts	M3.0 Adaptive Aid assigned
Video 13 (https://osf.io/fevz2/)	Arduino and automating your prints	M1.3
xx	Adaptive Aid show and tell	**Open_Source_3-D_Printing/Adaptive_Aid due**
Video 14 (https://osf.io/fcwpt/)	OS scientific hardware – lab partners	M4.1, M4.2, Scientific hardware project assigned
Video 15 (https://osf.io/rxvzq/)	Science Teams, OSH Sci Policy	Post lab partners-projects, M4.3
Video 16 (https://osf.io/ytc36/)	Science Teams - academic life	**Science prototype due (online post)**
xx	Test prototype, revise, trouble shoot	**Graduate students - choose project and list it on MOST Delta mods (http://www.appropedia.org/MOST_Delta_mods) or Automated 3D printable scientific equipment (http://www.appropedia.org/Automated_3D_printable_scientific_equipment)**
xx	Science Show and Tell	**Science revisions due, with data posted NIH/Github/Appropedia Gallery**
Video 17 (https://osf.io/uvkyd/)	Open source appropriate technology	OSAT project M5.1
Video 18 (https://osf.io/7ufvh/)	OSAT project	**OSAT project chosen**, M5.2
Video 19 (https://osf.io/q58dn/)	OSAT Project/Big Money Project-Sci+	**Big $ project Assigned**
Video 20 (https://osf.io/nq28f/)	Inventive thinking/OSAT Project/ Big Money Project-Sci+	mech properties ninjaflex (https://www.academia.edu/26772825/Tensile_Strength_of_Commercial_Polymer_Materials_for_Fused_Filament_Fabrication_3-D_Printing), Why the world needs deep generalists, not specialists (https://www.jotform.com/blog/the-world-needs-polymaths/)
xx	Inventive thinking/OSAT Project/ Big Money Project-Sci+	TRIZ 3D printers (http://www.appropedia.org/Category:4777_TRIZ_3D_printers) creative genius (https://ideapod.com/born-creative-geniuses-education-system-dumbs-us-according-nasa-scientists/)
xx	OSAT Show and Tell	**OSAT final due**
xx	Finish final projects	**Return Loaner Printers**
xx	Last day – The Future, Money Project-Sci+ and Grad	**Big Money Project, Graduate Project Due: MOST Delta mods (http://www.appropedia.org/MOST_Delta_mods) or Automated 3D printable scientific equipment (http://www.appropedia.org/Automated_3D_printable_scientific_equipment)**

Additional Readings and Media

OSL= *Open-Source Lab* textbook

Module 0: RepRap Build

1. Watch RepRap video (http://reprap.org/wiki/RepRap), The RepRap project- Ranellucci (https://www.youtube.com/watch?v=tBXdGznaN7E)
2. ~~RepRap build OSL Chap. 5~~, Athena II (http://www.appropedia.org/AthenaII), AthenaII part files (https://github.com/phidiasllc/athenaII) Need help go here https://groups.google.com/a/mtu.edu/forum/?hl=en#!forum/most-delta-users-l then use email: most-delta-users-l@mtu.edu
3. Software - Delta Software:MOST (http://www.appropedia.org/Delta_Software:MOST)(old), Slic3r (http://slic3r.org/), Cura (http://software.ultimaker.com/), Cura Lulzbot ed. (https://www.lulzbot.com/cura), RepRapPro Slicer (http://reprap.org/wiki/RepRapPro_Slicer), tweak AtoZ Cura plugin (http://www.3d4edu.com/hybrid-slicing-with-cura/), Matter Control (http://www.mattercontrol.com/)
4. Printer controllers - Printrun (http://www.reprap.org/wiki/Printrun), Franklin (https://github.com/mtu-most/franklin/tree/master/firmware) -- How to Install Franklin on your 777 printer (http://www.appropedia.org/Franklin:MOST), Franklin use video (http://most.mse.mtu.edu/franklin.avi), Using Franklin (long) (https://huskycast.hosted.panopto.com/Panopto/Pages/Viewer.aspx?id=716ea8c2-f078-450c-b7d1-fa6f3fe16e7e), Hacking Franklin (https://huskycast.hosted.panopto.com/Panopto/Pages/Viewer.aspx?id=feb39210-0629-4f95-b187-a452bf2588c9)

Module 1: Introduction to OSH

1. OSL Chap. 2 OSH Introduction, Cathedral and Bazaar (http://firstmonday.org/ojs/index.php/fm/article/view/1472/1387), Microsoft OSH (http://www.wired.com/wiredenterprise/2014/01/microsoft-open-compute-servers/), OSH intro video (https://www.youtube.com/watch?v=9xGRaPrcvVg), TEDxBoulder - Nathan Seidle (Sparfun)- How Open Hardware will Take Over the World (https://www.youtube.com/watch?v=xGhj_lLNtd0), Lulzbot factory tour and discussion of OSH business by Jeff Moe (http://diy3dprinting.blogspot.com/2014/02/lulzbot-factory-tour-and-open-hardware.html), The Law of Accelerating Returns by Ray Kurzweil (http://www.kurzweilai.net/the-law-of-accelerating-returns), Do Makers Propose a More Open Source Future? - Idea Channel, PBS Digital Studios (https://www.youtube.com/watch?v=ct5fjHC7tL8), 2015 the Year OSS went nuclear (http://www.wired.com/2015/12/2015-the-year-that-open-source-software-went-nuclear/), Can Open-Sourcing Transform Electronics Hardware? (http://electronics360.globalspec.com/article/6728/can-open-sourcing-transform-electronics-hardware), The Economics of OS (https://opensource.com/article/18/9/awesome-economics-open-source)
2. OSL Chap. 3 OS License OS License (http://opensource.org/licenses), Creative Commons copyright licenses (https://creativecommons.org/licenses/), OS software for GNU-Linux (https://prism-break.org/en/categories/gnu-linux/), The Future of 3D Printing: Smarter IP Strategies, Less Lawsuits (http://3dprintingindustry.com/2015/10/08/the-future-of-3d-printing-smarter-ip-strategies-less-lawsuits/), Right to Repair (https://www.wired.com/story/john-deere-farmers-right-to-repair/)
3. OSL Chap. 4 OS microcontrollers Arduino Tutorials (http://arduino.cc/en/Tutorial/HomePage#) , Makershed comparison (http://www.makershed.com/Articles.asp?ID=302), Jeremy Blum TED talk (https://www.youtube.com/watch?v=6LLzl-NuDjw), Nathan Seidle- SparkFun (https://www.youtube.com/watch?v=xGhj_lLNtd0)

Module 2: Community

1. RepRap IRC (http://webchat.freenode.net/?channels=reprap), RepRap Forums (http://forums.reprap.org/), RepRap Groups (http://forums.reprap.org/index.php?19), Lulzbot Forum Hacks (https://forum.lulzbot.com/viewtopic.php?t=2378)
2. Arduino Forum (http://forum.arduino.cc/), Arduino google group (https://plus.google.com/u/0/communities/114444064583962076057), MOST Delta Users (https://groups.google.com/a/mtu.edu/forum/?hl=en#!forum/most-delta-users-l)
3. Free and open repositories of designs (http://reprap.org/wiki/Printable_part_sources), http://www.yeggi.com/, Thingiverse (https://www.thingiverse.com/), http://www.stlfinder.com/ and now Wikimedia commons (https://blog.wikimedia.org/2018/02/20/three-dimensional-models/)
4. Tricks: support, raft, parts, orientation, fill, slicer choice, pictorial guide to problems (http://support.3dverkstan.se/article/23-a-visual-ultimaker-troubleshooting-guide),pictorial guide to reprap print trouble shooting (http://reprap.org/wiki/Print_Troubleshooting_Pictorial_Guide), RichRap Slic3r is Nicer (http://richrap.blogspot.com/2012/01/slic3r-is-nicer-part-1-settings-and.html), living hinges (https://www.matterhackers.com/news/living-hinge:--design-guidelines-and-material-selection), post processing (https://www.makerbot.com/post-processing/)
5. Appropedia (http://www.appropedia.org/), 777 demo page (http://www.appropedia.org/777_demo_page)

Module 3: Open source CAD

- Mech strength: Mechanical Properties of Components Fabricated with Open-Source 3-D Printers Under Realistic Environmental Conditions (http://www.appropedia.org/Mechanical_Properties_of_Components_Fabricated_with_Open-Source_3-D_Printers_Under_Realistic_Environmental_Conditions), The Effects of PLA Color on Material Properties of 3-D Printed Components (http://www.appropedia.org/The_Effects_of_PLA_Color_on_Material_Properties_of_3-D_Printed_Components), preprint for all materials (https://www.academia.edu/26772825/Tensile_Strength_of_Commercial_Polymer_Materials_for_Fused_Filament_Fabrication_3-D_Printing)

1. OpenSCAD (http://www.openscad.org/), OpenSCAD manual (http://en.wikibooks.org/wiki/OpenSCAD_User_Manual), MOST SCAD Libraries on Github (https://github.com/mtu-most/most-scad-libraries), Object oriented OpenSCAD (http://www.appropedia.org/Object_oriented_OpenSCAD), RapCAD (https://github.com/GilesBathgate/RapCAD), Aaltoblock (http://www.appropedia.org/Aaltoblock), Customizer Thingiverse Format (https://customizer.makerbot.com/docs)
2. Blender (http://www.blender.org/), Using Blender to Model for 3-D printing (https://www.youtube.com/playlist?list=PL9MUC-YxhJ6BwWXXNu9THB4k4KcrsEkA9) , 2D to 3D in Blender (http://www.youtube.com/watch?v=-fe2zxcKSic), Creating 3D models for printing with Blender: Advanced tips (https://opensource.com/life/16/8/creating-3d-models-printing-blender-advanced-tips), Blender Design on Curved Surfaces Tutorial (http://www.appropedia.org/Blender_Design_on_Curved_Surfaces_Tutorial)
3. FreeCAD (http://www.freecadweb.org/), Bram de Vries FreeCAD video tutorials (https://www.youtube.com/user/boumdadaque/videos) Using OpenSCAD tricks in FreeCAD (https://www.youtube.com/watch?v=Q_yHME82jW8)
4. Tricks - Multicolor (http://www.3d4edu.com/live-feeding-new-filament-updated-extruder-drive/), 3D print from McMaster-Carr (https://www.matterhackers.com/articles/3d-print-hardware-from-mcmaster-carr), 3DHubs - how to optimize design for FFF (https://www.3dhubs.com/knowledge-base/how-optimize-your-design-fdm-3d-printing)
5. Converting 2D images to 3D for printing using open source software (http://www.appropedia.org/Converting_2D_images_to_3D_for_printing_using_open_source_software), Images to OpenSCAD Via Inkscape (http://www.thingiverse.com/thing:25036), Celtic Knot SCAD (https://github.com/beanz/celtic-knot-scad), Bezier curves and knots script for Blender (http://www.thingiverse.com/thing:56629)
6. MOST Delta mods (http://www.appropedia.org/MOST_Delta_mods) - see also: Github MTU-MOST repositories (https://github.com/mtu-most?tab=repositories), Open-source syringe pump (http://www.appropedia.org/Open-source_syringe_pump), Open-source metal 3-D printer (http://www.appropedia.org/Open-source_metal_3-D_printer), MOST mods (incomplete but getting there) (http://www.appropedia.org/Multi-material_additive_and_subtractive_prosumer_digital_fabrication_with_a_free_and_open-source_convertible_delta_RepRap_3-D_printer), another approach to PCB design (http://www.lamja.com/?p=635)
7. Open Source Photogrammetry (http://www.appropedia.org/Open_Source_Photogrammetry), Open source 3D scanners (http://www.appropedia.org/Open_source_3D_scanners), Lithopanes (http://3dp.rocks/lithophane/)

Module 4: OS Science

1. OSL Chap. 1 examples 3D printable science equipment (http://www.appropedia.org/3D_printable_science_equipment), Tekla Lab requests (http://www.teklalabs.org/how-to-contribute/)
2. OSL Chap. 5
3. OSL Chap. 6
4. OSL Chap. 7

Module 5: OSAT

1. The Case for Open Source Appropriate Technology (http://www.academia.edu/1517361/The_Case_for_Open_Source_Appropriate_Technology), 3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development (https://www.academia.edu/1507915/3-D_Printing_of_Open_Source_Appropriate_Technologies_for_Self-Directed_Sustainable_Development), Open source 3-D printing of OSAT (http://www.appropedia.org/Open_source_3-D_printing_of_OSAT), How 3D Printers Are Boosting Off-The-Grid, Underdeveloped Communities (http://motherboard.vice.com/read/how-3d-printers-are-boosting-off-the-grid-underdeveloped-communities) - MotherBoard
2. Recyclebot (http://www.appropedia.org/Recyclebot), Open Source Ecology TED talk (https://www.youtube.com/watch?v=S63Cy64p2lQ)

Other

1. Post processing (https://www.3dhubs.com/knowledge-base/post-processing-fdm-printed-parts)
2. 3DP for injection molding (https://pinshape.com/blog/low-cost-injection-molding-using-3d-printing/)
3. MyMiniFactory's Design Handbook (https://docs.google.com/presentation/d/e/2PACX-1vScQctxNThshI6gABfS40jq2_RgW3-pu-AnvuqyTfJgawVgkXKMBMx5bEqRdz611--hVmZJUrg371Xy/pub?start=false&loop=false&delayms=60000#slide=id.p)
4. The Economist-- A third industrial revolution (http://www.economist.com/node/21552901), Where we go from here - types of OS3DP OS metal 3D printer (http://www.appropedia.org/Open-source_metal_3-D_printer)

Other good watching: First International Workshop on "Low-cost 3D Printing for Science, Education and Sustainable Development (https://itunes.apple.com/us/itunes-u/first-international-workshop/id688831895), 25. Hopes and Fears, 27. Open Hardware and Arduino, 31. Prehistoric Collections: Digitizing the Leaky collection and interesting perspectives on digital rights and proprietary museum collections, 33. Bringing a CAD model into a physical object: Ranelucci video, 54. The future of 3D printing: Another Ranelucci video.

Educational level: this is a tertiary (university) resource.

Type classification: this resource is a course.

Subject classification: this is an engineering resource.