Self-Replicating Open Source Rapid Prototyping in the Engineering Classroom

DAVID B. SAINT JOHN,

Ph.D. Candidate in the Materials Science and Engineering Department at the Pennsylvania State University. In addition to reprap-related efforts, his primary research is currently focused on the use of spectroscopic ellipsometry and transmission electron microscopy for characterization of amorphous hydrogenated germanium thin films.

ERIC M. FURJANIC

Graduate of the Department of Anthropology at the Pennsylvania State University, Eric is a co-founder of the State College Reprap Users Group and Intercollegiate Future Society. He recently finished work as a contributing editor for Philip K. Dick's posthumous work: *Exegesis*, and plans to continue helping develop low-cost DIY genetics applications for the Reprap.

RICHARD DOYLE,

Professor of English and Information Sciences and Technology at the Pennsylvania State University, he is also the author of a trilogy of books on information and the life sciences. The latest, Darwin's Pharmacy: Sex, Plants, and the Evolution of the Noösphere, was published by the University of Washington Press in 2011.

RICHARD DEVON

Professor of Engineering Design, Engineering Design Program, SEDTAPP, Penn State University. He was Interim Director of the Science Technology and Society Program for two years, Director for six years of the PA Space Grant consortium, and founding Director of the Engineering Design Program. He teaches, researches, and publishes on design education, with current interests in using the Cloud computing, global design, and rapid prototyping.

Self-Replicating Open Source Rapid Prototyping in the Engineering Classroom

From its genesis as a lark in the home basement lab of the senior author in the fall of 2010, the [Area] Reprap Project grew rapidly. It was offered a a group research project in Spring semester 2011 and 10 students quickly signed up and spent the semester building three functional RepRap fused-filament printers. In Fall 2011, it has evolved into an innovative course using a wiki as its textbook, a grading system based in “experience points” (XP), and self-directed “missions” chosen by students according to their interests in exchange for a predetermined amount of XP. This resulted in an intensely productive, highly collaborative fab-lab environment where students are successfully assembling four more RepRap printers. In spring and fall they have also learned to produce computer models with a 3D scanner to be used as printable files, designed and printed upgrades to the machines, and gave back to the RepRap open source community by filling in what gaps they could in the public documentation. These printers, in turn, have been used to produce the structural components for four more Repraps of our collective’s own modified design which will be the starting project of our now heavily-overbooked second iteration of the RepRap RPG course.

Our class’ structure mimics the work of Professor Lee Sheldon of Rensselaer Polytechnic Institute, who found that class participation, attendance, and grades improved when he switched from a percentage style grading system - where a student begins the semester with 100 percent and loses points from there - to one styled like a role playing game (RPG) where a student begins at level ene with 0 experience points (XP) and earns cumulative XP throughout the semester in order to “level-up” their grade. Like many modern multiplayer games, our class included achievements with small rewards for notable achievements and incremental progress, as well as missions; previously defined or student-proposed projects worth agreed-upon set amounts of XP.

A strange hybrid between low-tech and high-tech, the Reprap project stands as a striking example of an emergent technology which rides the cutting edge not because it has never been done before, but because it has never been in the hands of the global community before. Such a project would not have been possible a few years ago, when the cheapest 3D printers cost the same as a comfortably accoutered automobile and all the technology driving them was, and still remains, zealously guarded as proprietary intellectual property. Thanks to all of these contributions to the public domain, hands-on experience with computerized materialization is now an affordable possibility in the classroom; the CAD models created by students are no longer simply useful for generating schematics, but can become something tangible.

.

Introduction

This text seeks to report recent rewarding efforts which have taken place at [University Area], integrating open source 3D printing technologies into an educational environment using both labs and lectures. This work has not been the product of any ‘top-down’ grants or external funding, but was a true ‘bottom up’ development, which we believe to be capable of a wide range of scalability. We emphasize this for the sake of educators who may write off this type of project as being beyond their budget - in lieu of funding - we hope to provide encouragement to the interested.

A Brief Background on RepRap Technology

A number of evolutions, variations, and improvements from both commercial vendors and the open-source community have led to a generation of 3D printers which cost approximately 3% of a commercial machine’s retail value, have a tool-chain of entirely open-source programs avilable to run them, and can use the inexpensive bio-degradable thermoplastic polylactic acid (PLA) as a feed stock while still producing models with more structural integrity than many much more expensive powder printers.

One of the precursors to this development was the debut of the programmable, publicly licensed, open-hardware Arduino micro-controller, which has drastically modified the breadth and depth of do-it-yourself (DIY) projects over the past several years. The project, founded by Massimo Banzi and David Cuartielles, emerged from a synthesis of a number of projects and contributions, such as Hernando Barragán’s senior thesis - an open source micro-controller programming language with an integrated development environment (IDE) called “Wiring” which evolved out of “Processing” by Casey Reas and Ben Fry.

Among the most visible advances in 3D rapid prototyping enabled by the Arduino is the RepRap Project. RepRap is short for replicating rapid prototyper; a machine designed to be made of pieces it could print itself. This is in stark contrast to the expensive non-self replicating designs which have dominated the commercial prototyping market for the last 30 years.

The RepRap project was started by professor Adrian Bowyer in 2005, whose first RepRap design, the “Darwin,” would be released to the open source community in 2007. His graduate student, Edward Sells, would later redesign the RepRap Darwin, producing what is now known as a “Mendel” design.

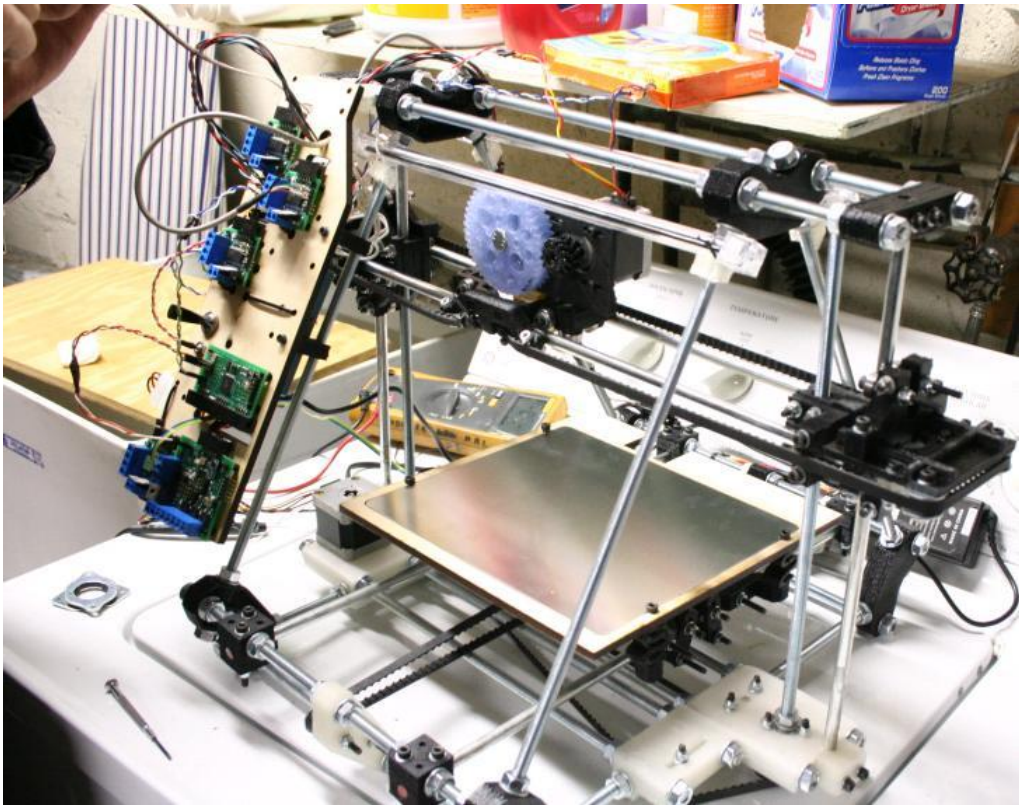

Fig. 1. A RepRap Mendel.

These designs are not the terminus of the RepRap project, though they are likely the end of any 'official' variants as Professor Bowyer has expressed that the open source movement itself will decide what future variants are worth development and production, without any authoritarian fiats from 'above'. Many of the various RepRap designs being field tested can be seen at the RepRap Family Tree - including that of our own class' design, the [Model Name] Mendel. (http://reprap.org/wiki/RepRap_Family_Tree).

Specifications vary somewhat depending on the breed of Reprap, but a standard Mendel occupies a volume of 500 mm (X) by 400 mm (Y) by 360 mm (Z), and has a build envelope of 200 mm (X) x 200 mm (Y) x 140 mm (Z). In addition to PLA, it can print acrylonitrile butadiene styrene (ABS) so long as it has a heated print-bed.

RepRap RPG 1.0: A Course for all Majors

In October 2010, a laser-cut wooden reprap mendel kit was purchased with personal funds from one of several available online vendors by one of the authors. This system was producing useful parts by December 2010, and a course was posted with little notice for spring 2011. This spring class of 11 students met once per week, and was able to assemble and perform some troubleshooting on two Mendels and a Huxley in the course of the semester. In tandem with this, students learned to operate a 3D scanner in order to create models, and designed, printed and tested both a filiment spool and a pen-plotter modification. These printers are now the parents of the four Repraps being built in RRRPG 2.0 for our fall semester, and our electronics team is attempting to use last season's pen-plotter to etch PCB electronics boards of our own improved design for future classes.

Our class' grading structure is loosely based on the work of Professor Lee Sheldon of Rensselaer Polytechnic Institute, who found that class participation, attendance, and grades improved in his classes when he switched from a percentage style grading system - one where a student begins the semester with 100% and only loses points from there - to one styled like a role playing game (RPG), where a student begins with zero experience points (XP) and earns them throughout the semester in order to "level-up" their grade.

In our version, students could gain XP in a number of ways. Simply showing up, contrary to Woody Allen's estimations, calculated out to be worth 53% of the XP needed for an A. Taking a cue from the psychology behind modern game design, we implemented "achievements" with small XP rewards to incentivize activities such as participating in class lectures, taking the 'print-license' test, or learning to use more complex G-Code generators in order to improve object quality.

The most central element of the experience point system, however, is that allows for missions; previously defined or student-proposed projects worth agreed-upon amounts of XP. The first mission given to every student was a mandatory one involving a small team effort to assemble a functional RepRap printer. Once completed, students can then choose to undertake any missions they please from a master list of projects which aim to improve the local fab-lab or RepRap community as a whole. These include tasks such as modifying structural models to remedy design flaws found by the group or learning how to retrofit heated print-beds onto our machines to enable use of new types of filament. This non-linear system also encourages student innovation by allowing them to propose their own projects for approval by the instructors, leading to such interesting projects as that of one student who developed code capable of transforming atomic force microscopy data (AFM) into printable topography.

We calibrated the value of XP in our system to the [University Name's] expectation that each credit hour taken for a semester should involve 40 hours of dedicated, focused involvement on the part of a student. By defining 100 XP as equivalent to one hour of "gear time," we decided Level 12 would be our A level for three credit students, set at 12,000 XP. Attendance, defined in our syllabus as "being here and not useless," would net students 200 per session, totaling 6400. Since we knew the RepRap build projects themselves would likely take half of the semester, we set that mission's maximum reward at half of the non-attendance points needed by an A student - 3000 in this case. The remainder of their points would be composed of completing other missions, achievements, and contributions to the wiki.

Our experiences have been akin to Professor Sheldon's: We find that our students are highly motivated to participate and contribute to the course - each sculpting their own class experience to suit their strengths, entertain their interests, or improve upon areas in which they feel inexperienced. While the course was listed under the Department of Engineering Design, it was predominantly populated by undergraduates from electrical engineering, mechanical engineering, and aerospace programs.

Replication and Mutation of RepRap RPG

There are two aspects to the course described above which other educators may have interest emulating, either together or separately: using RepRap technology in a classroom setting, and operating the course using an RPG-derived points system. These two parts have seemed to be synergistic in our experience, but it is worth discussing their merits and variability separately.

With regard to using RepRap in the classroom, one can imagine discipline-specific courses which cover topics in addition to the general assembly, operation, troubleshooting, and maintenance which comes with the territory. Some suggested topics are listed below:

a. Physics: heat dynamics, electronics, static forces, friction, etc.
b. Engineering Design: Solidworks/Sketchup/Blender/Openscad - (re)design and print
c. Materials Science: Discussions of relevant polymers, metals, insulators, etc.
d. Art/Sculpture: Reprap as a Medium
e. Electrical Engineering: RepRap-created electronics for RepRaps
f. Computer Programming: Firmware, software, G-Code refinement
g. Mechanical Engineering: Building/modifying Repraps, analysis of currently used designs
h. Law/Ethics: Patents, design, and desktop fabrication
i. Psychology: Prototyping and cognition

With scalable, customizable, hands-on 3d prototyping experiences at relatively low cost for college or high school classrooms, this type of project provides plentiful opportunities for interdisciplinary collaboration.

The merits and flaws of the RPG grading system deserve better analysis than will be given here, but the inspiration for their use is a presentation by which gives some insight into how one might approach the use of such a grading system[1]. When considering whether or not to use an 'RPG-like' point system for class operation it is important to consider that the grading is inevitably more involved than traditional grades, depending on the complexity of the point system in use. Sheldon's own syllabus[2], along with tools for designing your own version[3], are available online for open source remixing.

Future Endeavours and Visions

In addition to redesign and printing of models, building of repraps, and other assorted projects, there are several other interesting projects that are an easy next step. Combined with a 3D scanner, students were able to import structures from the real world for replication, and the number of open source 3D scanning platforms is growing.With the collaboration of Professor [John Doe] of the Anthropology Department, our students will be able to scan and print their own faces. With the involvement student robotics club, we are currently planning to help build parts for either a bipedal robot or a quadracopter. Most ambitious yet most developed of all is our prototype of an alternative toolhead and print-bed which, like an "app," would allow a standard Mendel to preform automated polymerase chain reactions in order to amplify DNA for low-cost testing.

Summary

Thanks to all of these contributions to the public domain, hands-on experience with computerized materialization is now an affordable possibility in the classroom; the CAD models created by students are no longer simply useful for generating schematics, but can become something tangible and useful. At the crossroads of so many fields, this project not only teaches students about a new and popular technology, but gives them an environment where their projects are not discarded or deleted at the end of the semester; rather, they live on as contributions to the overarching body of collaborative work at the heart of the global Reprap project, growing it larger, piece by piece.

Citations

[1] http://g4tv.com/videos/44277/DICE-2010-Design-Outside-the-Box-Presentation/

[2] http://gamingtheclassroom.wordpress.com/syllabus/

[3] http://terranova.blogs.com/terra_nova/2010/03/build-your-own-sheldon-syllabus.html