Developing Printable Content
A Repository For Printable Teaching Models

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Abstract

Alongside the development of RP technology, there is an increasing need to develop and share printable content. Like digital photography and digital music, content drives technology as much as technology drives content. This paper describes the development and population of an open wiki-style website (**3Dprintables.org**) that houses an archive of printable models for education. These models are intended to serve as "seeds" to encourage educators to further develop and share printable models and the associated curricular materials.

Motivation

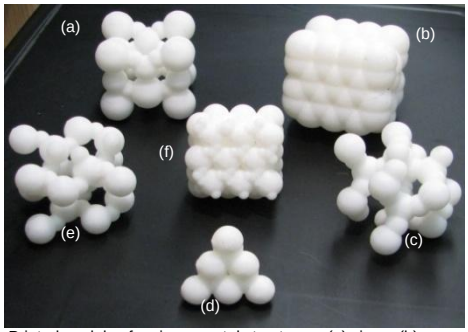
C_{60} Fullerene "Buckyball"

Physical models have always been an important teaching aid, especially in math and the sciences. It is well established that learning is enhanced for many students when physical models are included in their curriculum. Recently, however, computer simulations have been replacing physical models because of cost and customizability advantages.

While computer models and simulations are a valuable resource for many students, they are not a sufficient substitute for manipulating a physical model. Manipulative models help students develop spatial reasoning skills, which in turn leads to improved performance in math, science, and engineering. Developing these skills early in the educational system could encourage more students to choose a career in science or engineering.

Physical models are also an essential learning tool for blind and visually impaired students. Faced with a lack of available models, teachers are forced to spend their own time and money to construct models for their students.

This project aims to address these needs by providing a free archive of printable teaching models and tools for model creation. These models can be printed with rapid prototyping systems that educational institutions already own.

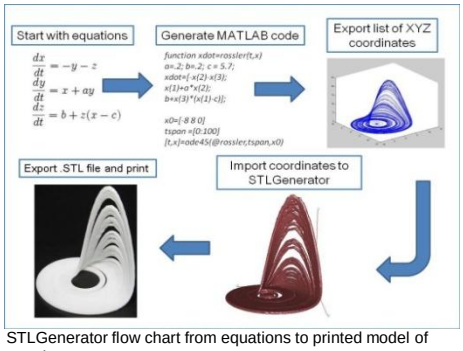


Printed models of various crystal structures. (a) zircon (b) graphite (c) β-quartz (d) diamond (e) α-quartz (f) calcite

Tools for Model Generation

One barrier to accelerating the development of printable 3D content is the high specialization of CAD programs. These programs also require a significant amount of training time before the user can begin generating useful parts. A few simpler tools are available to create and edit .STL files, but these programs can be expensive. There is a need for free, easy to use .STL processing tools to encourage the development of printable content.

STLGenerator is an open source utility for viewing and generating STL files from data. It can create an STL file directly from a list of points, line segments, surfaces, and PDB molecule files. The software uses the Marching Cube algorithm (Lorenson, 1987) to tessellate an iso-surface defined around a set of points or curves. A variety of options are available for generating partial models (selected chains in a large molecule), as well as adjusting atom size and curve widths, etc.



STLGenerator flow chart from equations to printed model of Rössler Attractor.

Creating the Models

Models were chosen in 3 ways:

1. Physical representations of topics foundational to many high school and introductory college curricula (ex: strange attractors, revolutions about axes, phage).
2. Models already freely available on the internet (ex: proteins, crystal structures, pyramids).
3. Models requested by educators based on their experiences in the classroom.

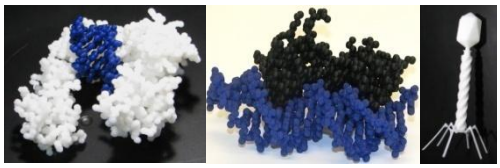
Sample Curricular Material

Lagrange Multiplier model made for Prof. Maria Terell (Cornell University, Mathematics) and a portion of her curriculum

"When looking for the extreme values of a differentiable function f, subject to two constraints, g=0 and h=0, often the gradients of ∇g and ∇h are not parallel. In such cases ∇f is a linear combination of ∇g and ∇h. It is often difficult for student to visualize the two intersecting surface, the tangent to the curve of intersection, the gradients which at perpendicular to the surfaces, and the gradient of f. This model helps students see that ∇f lies in the plane determined by the gradients to the level sets, and that that plane is perpendicular to the tangent to curve determined by the intersection of the surfaces g=0 and h=0. Hence it is more readily apparent why the optimal solution should satisfy $\nabla f = \lambda \nabla g + \mu \nabla h$ and g(x,y,z)=0, h(x,y,z)=0"

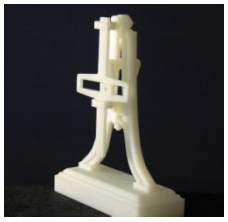
Sample Models

Biology



DNA polymerase (left), DNA binding factor (center), T4 phage (right) Protein models can be generated directly from Protein Data Bank (PDB) files. The two above were made from PDBs 1kln and 3cro respectively. The T4 phage was modeled in SolidWorks.

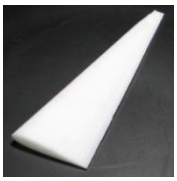
Kinematics



Double Slider Crank

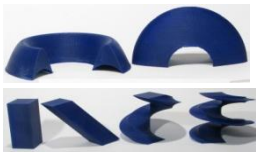
Worm Drive

Aerodynamics



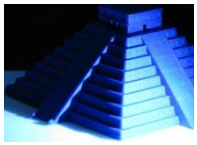
Clark Y and high-lift wings (left) and Boeing 737 wing (right)

Mathematics



Lorenz Attractor (left), revolved solids (top right) and illustration of the Cavalieri's Principle (bottom right)

Archeology



Simulated sunset on the equinox at El Castillo, Chichen Itza (left) and cuneiform tablet (right)

Make Your Own Models

The tools available at **3Dprintables.org** require no prior experience with 3D printing or CAD software. A novice user can begin creating models within minutes of downloading the software. This feature of the site is essential to empowering educators to create their own models and post them on the website to share with others.

ACKNOWLEDGEMENTS

This work was supported in part by the U.S. National Science Foundation CAREER award # CMMI 0547376. Special thanks to: Professor Maria Terell, Cornell Mathematics Department, Erik Dierkx, Michael Book, Bill McKeeman, David I. Owen, Evan Malone, RCSB Protein Data Bank (PDB), UIUC Airfoil Coordinates Database, Bacteriophage Ecology Group (Ohio State – Mansfield), Crystal Lattice Structures (Navy Research Laboratory), Kinematics Models for Design Digital Library (KMODDL).

SELECTED REFERENCES

Cohen, H.G. (1983). "A comparison of the affect of two types of student behavior with manipulatives on the development of projective spatial structures." *Journal of Research in Science Teaching,* 20(9), 875-883.

Lipson (2007). "Printed 3D Models for Customized Hands-On Education." *Proceedings of Mass Customization and Personalization (MCPC)* 2007.