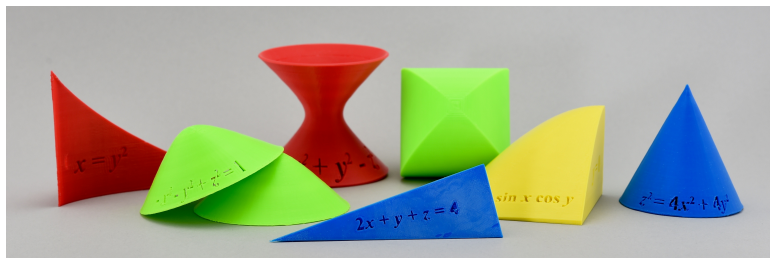# Calculus, Topology and 3D Printing

Elizabeth Denne

Washington & Lee University

Enhancing Mathematical Learning with 3D printing.
SIAM Conference, September 30, 2016.

Introduction to Topology, Fall 2014

Models for Teaching, Summer 2015

3D printing in the classroom

1. Make manipulatives and visualizations.
   - Volumes by slices, washers or cylindrical shells.
   - Quadratic surfaces, other volumes (triple integrals).
   - Curves, knots, other geometric surfaces.

2. Students design and 3D print objects.
   - Use 3D printing in a class project.
     - Models should enhance mathematical understanding.
     - Projects include a writing component.
   - (Future) Build a course around 3D printing.
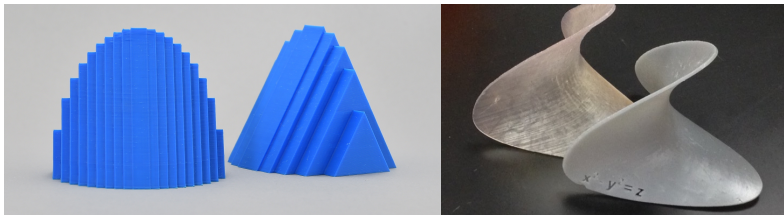
Basics of 3D print design

1. Think about model you want to create.
2. Model it in *Mathematica* (maybe).
3. Import into, or design model entirely in 3D design software.
4. Export .stl file.
5. Open file in 3D printer's software, choose size, scale, supports, print quality, etc, producing a print file.
6. File is then printed by 3D printer (or not).

Software

- *Mathematica*, Maple (both $).
- TinkerCAD, OpenSCAD (both free).
- Cinema4D ($), Rhinoceros ($), Blender (free).
- Meshlab, TopMod, Grasshopper, others.

Set up at W&L

IQ (Integrative and Quantitative) Center in Science Center.

- Classroom spaces:
    - Stereo 3D lab,
    - Computer Visualization Lab.
- 3D printing (Physical/Mechanical Lab)
    - FormLabs Form 1+ printer,
    - ProJect 260 - 3D System,
    - MakerBot Replicator 2X, uPrint SE, Series 1 Pro.
- Secret weapon: Dave Pfaff.
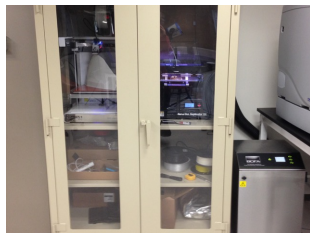
# Introduction to Topology, Fall 2014

Project - week 5

- Each person (group) designs a topological/mathematical object that can be 3D printed.
- Write a 1 page description of
    - the mathematics of the object,
    - how the object was designed in 3D, and how any design problems were solved.
- Can't download already existing objects.
- Grade is the same as a weekly homework assignment.

Notes

- 3 class periods spent on the project.
- Project came after material on quotient spaces.
- Project was an excuse to introduce some knot theory.

Introduction to Topology, Fall 2014
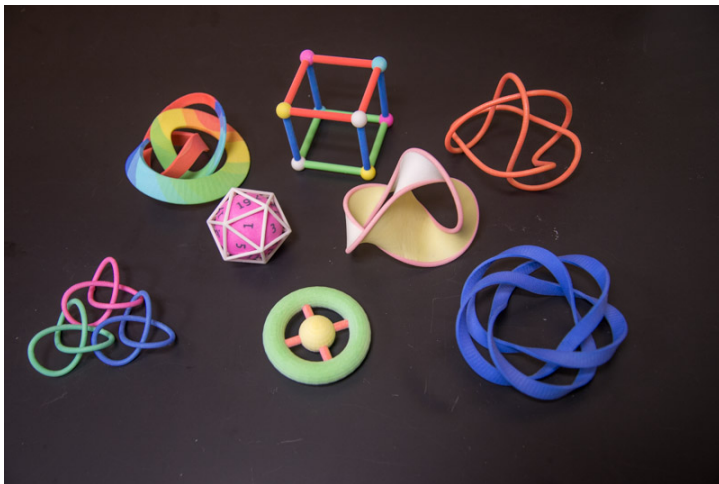
What I learned

- This was the students favorite part of the course!
- Students need time to learn to use software.
  - Need explicit (project related) instructions on how to use Cinema 4D.
- Project was too open ended.
  - Give a list of suggestions of objects to design.
- Mathematical description of object was often lacking.
  - Adjust the writing requirement.
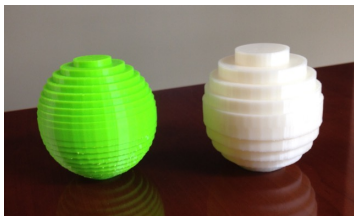- Objects needed extra editing for clean 3D design.
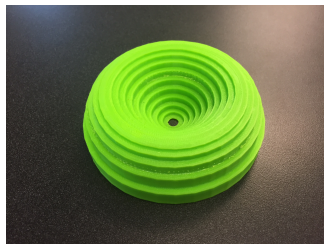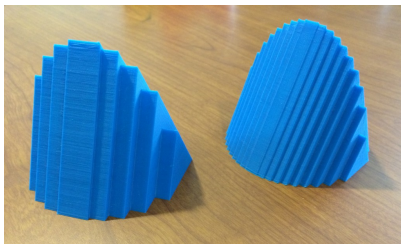
Summer 2015

W&L Summer Research Scholars:
> Emily Jaekle ('16) and Ryan McDonnell ('17).
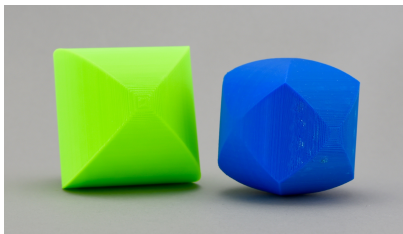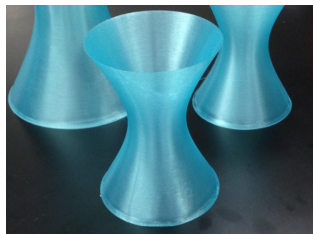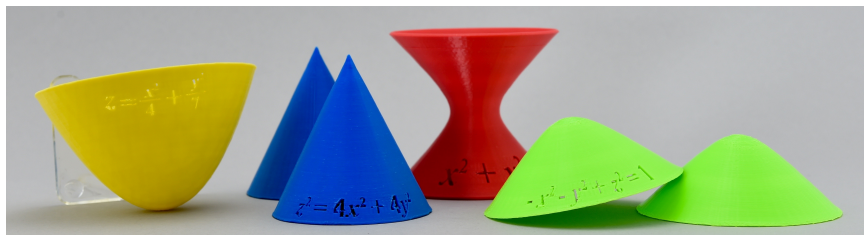
Together we designed and wrote:
> 46 math models, 11 instruction sheets, 9 *Mathematica* worksheets, many blog entries.
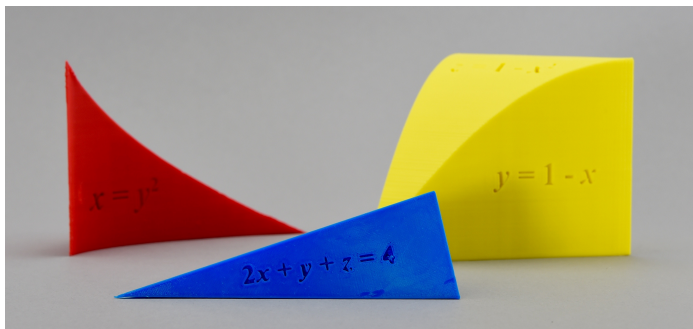
Volumes by slices
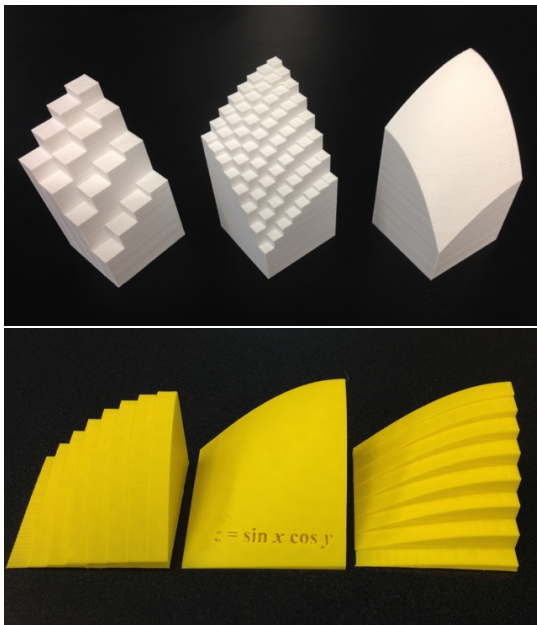
Quadratic & Steinmetz surfaces

Volumes with equations
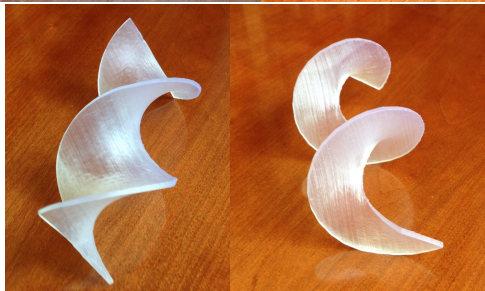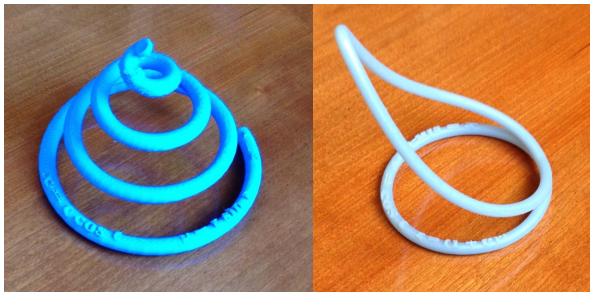
Model design

- Design object (in *Mathematica* or in Cinema 4D).
- Add equations in Cinema 4D.
    - Find appropriate font, and thicken equations.
    - Use *Bend* tool and *Boole* tool to add equations.

Explaining Double Integrals

Geometry of curves and surfaces

Calculus II Fall 2016

Project: Volumes by slices.

- Students work in groups (3 people).
- 3 class periods.
- **3D modeling.**
  - Learn how to use Cinema 4D by building a volume of revolution (disk/washer method).
  - Build a more complex volume illustrating: cylindrical shell method and/or a volume by slices.
- **Writing.** For each volume:
  - Give details of mathematics of each slice.
  - Describe any 3D design problems and their solutions.
  - Compute integral to find the volume.
- We will 3D print a subset of the models.

Multivariable Calculus Spring 2017

- Existing course requirement for students to be familiar with a program like Maple or *Mathematica*.
- Currently have 6 *Mathematica* labs over the semester.
- *Mathematica 11* is 3D printer friendly (?!)
- Existing labs can be adjusted for 3D printing.
- Try 2 smaller 3D printing projects
    - Curves (either level curves or spatial curves)
    - Volumes for integration.

- Watch this space!
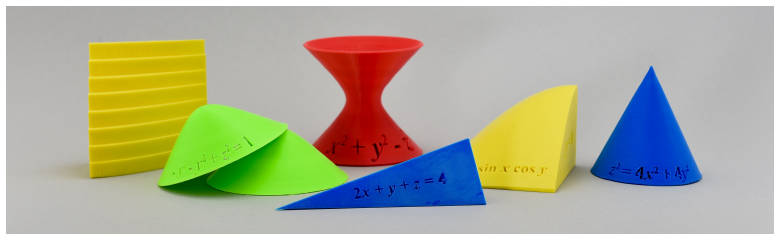
More information

My webpage: **Math Visualization**

All of these models are found on my **Thingiverse page**.

My blog: **Visions in Math**.

Thank you

Dave Pfaff & the WLU IQ center,

and

Emily Jaekle ('15) & Ryan McDonnell ('16),

and

My Fall 2014 Math 341 Introduction to Topology class.