3D Printing & Arduino in the ChE Classroom: Protein Structures, Heat Exchangers, and Spectrophotometers

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Goals

ChE students may complete several design simulations/projects, but they rarely get a chance to design and build prototypes.

3D Printing & Arduino/Pi make it easy & cheap to build prototypes.

Goal 1: Enhance student learning.

Goal 2: Introduce students to drafting, coding, etc.

Goal 3: Give the students an opportunity to be creative!
Module 1: Dihedral Angles in Proteins

Students do not need to know CAD or coding for this module - they just play with 3D printed parts!

- The peptide backbone in a protein has 3 unique dihedral angles: \( \omega, \psi, \) and \( \phi \)
- \( \omega \) is fixed, but \( \psi \) and \( \phi \) can rotate between 0-180°
- Steric hindrance makes some angles more favorable
- Some angles provide unique 2’ structures – \( \alpha \) helices + \( \beta \) strands
3D Printing Proteins

- Tripeptide = Gly-Ala-Gly
- 26 atoms
- 7 unique pieces
- 14 parts
- Parts connected by tubing
- Dials show dihedral angles
- 2 pieces for tetrahedrons
- Peptide bond is planar

Note: Additional side chains can also be included.

Activity 1: Ramachandran Plot
Activity 2: $\alpha$ helices + $\beta$ sheets
Beta Strand: $\phi = \psi = 180$
Student Feedback

Student Comments:
• Assembly
  • Joints were a little hard to work with, models could be assembled incorrectly
• Timing
  • Need more time for assembly, maybe send a kit home for review?
Module 3: DIY Spectrophotometer (Colorimeter)
Freshman Interdisciplinary Engineering Design Course (EGR 1200)

Spectrophotometers are commonly used to measure concentrations, enzymatic reaction rates, etc.

Unfortunately, they can also be quite expensive ($>1,000)......

However, spectrophotometers are based on a relatively simple principle:

![Diagram of spectrophotometer components]

If you only need to measure a specific wavelength (e.g. 420 nm for ONP), then this design can be simplified by just using a (blue) LED as a light source and photoresistor as a detector.

![Chemical reactions and molecules]
This is a minimal design that students are allowed to modify. Most groups add covers for the cuvette. Some groups make enclosures for the circuit. One group designed a device that could monitor 2 cuvettes!
Standard Curve: O-nitrophenol (ONP)

Trends obtained with the devices are identical to a commercial spectrophotometer.

β-galactosidase Reaction:
Enzymatic conversion of ONPG $\rightarrow$ ONP

The device detects changes in reaction rates ($V_o$) from varying substrate concentrations, which can then be used to prepare a Michaelis-Menten plot.

$V_{max} = 138 \pm 25.1 \frac{\mu\text{mol ONP}}{\text{min-mg} \ beta gal}$

$V_{max} = 134 \frac{\mu\text{mol ONP}}{\text{min-mg} \ beta gal}$

$K_m = 0.92 \pm 0.12 \text{ mM}$

$K_m = 0.95 \text{ mM}$
## Summary

<table>
<thead>
<tr>
<th>Module</th>
<th>3D Printed Parts (Thingiverse IDs)</th>
<th>Arduino?</th>
<th>Available Materials</th>
<th>Cost/Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peptides</td>
<td>2758246 (Tubing) 2509708 (Screws)</td>
<td>No</td>
<td>Videos PPT Slides Activities Stickers</td>
<td>$1.50</td>
</tr>
<tr>
<td>Plate &amp; Frame</td>
<td>2452341</td>
<td>Optional</td>
<td>PPT Slides</td>
<td>$5-50 + pumps, baths</td>
</tr>
<tr>
<td>Colorimeter</td>
<td>2760937 (Cuvette) 2456868 (Flow Cell)</td>
<td>Yes</td>
<td>Lab Manual PPT Slides Example Data Arduino Code</td>
<td>$50/device $500 for reagents</td>
</tr>
</tbody>
</table>

Please contact me (jacob.elmer@villanova.edu) if you have any interest in using these modules.
Thank you for coming!

Acknowledgements:
Villanova University - Freshman Design Miniproject Grant
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Students – William Landis, Brianna Conte, Neill Boyce, Jeffrey Neuhaus

This is 3D printed!
Links + GIFs

• Amino acids with screws: [https://www.thingiverse.com/thing:2758246](https://www.thingiverse.com/thing:2758246)
• Amino acids with tubing: [https://www.thingiverse.com/thing:2509708](https://www.thingiverse.com/thing:2509708)
• Dihedral Demo: [https://www.youtube.com/watch?v=1usemtlYe_s](https://www.youtube.com/watch?v=1usemtlYe_s) (3213 views!)
• α/β Demo: [https://www.youtube.com/watch?v=4x61Je8UWsE](https://www.youtube.com/watch?v=4x61Je8UWsE) (314 views...)
• 3D CAD Protein models: [https://biologicmodels.com/](https://biologicmodels.com/)  [https://3dprint.nih.gov/create](https://3dprint.nih.gov/create)
• Magnetic models: [https://makezine.com/projects/peppytides/](https://makezine.com/projects/peppytides/)
Parts + Links

• CAD + STL files:
  • Cuvette holders: https://www.thingiverse.com/thing:2760937
  • Flow cell: https://www.thingiverse.com/thing:2456868

• Other colorimeter designs:

• Student Survey Results

  0-5 scale
  0 = strongly disagree
  5 = strongly agree

  Overall value of this course
  I learned a great deal in this course.
  I found the course intellectually stimulating.

  Strongly Disagree 0 1 2 3 4 5 Strongly Agree
  n = 42
3D Printing Primer

- 3D Printing is now easier, cheaper, and faster than ever
- Make/download a part, convert it into G-Code, and print it yourself/online
- Online tutorials are available for every step
- Parts can be hollow, metal, flexible, etc.

Design part(s) in CAD Program (Solidworks) or download (www.thingiverse.com)

Convert .STL file into .gcode (Cura)

Print! Use a 3D printer (Taz 6) or order online.

$1,250-$50,000

www.shapeways.com
Module 2: Plate & Frame Heat Exchanger

Our Heat Transfer course had a heat exchanger design project, but no lab component...

..so I introduced an Honors design project on 3D printing a Plate & Frame heat exchanger:
Parts + Links

- Plates (top, middle, bottom): [https://www.thingiverse.com/thing:2452341](https://www.thingiverse.com/thing:2452341)
- Vacuum-formed Heat Exchanger