

# Impact of 3D-printed molecular models on teaching protein and DNA structure



ALEXANDRU IOAN CUZA UNIVERSITY of IAȘI

www.uaic.ro

**Marius Mihășan, PhD.**

Faculty of Biology

Alexandru Ioan Cuza University of Iași, Romania

E-mail: [marius.mihasan@uaic.ro](mailto:marius.mihasan@uaic.ro)

<https://3dprint.nih.gov/users/mariusmihasan>

# A bit about us and our work in Iași

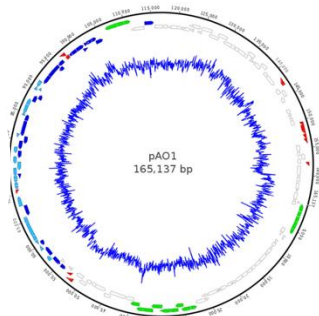
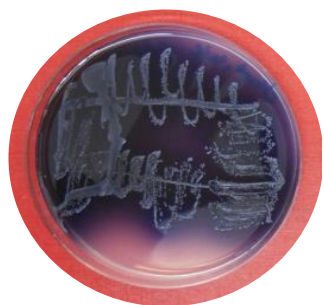


ALEXANDRU IOAN CUZA UNIVERSITY of IAȘI

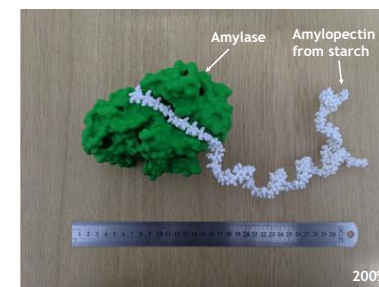
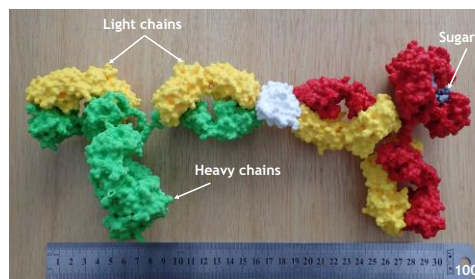
www.uaic.ro

## Main research subjects:

- molecular biology of pAO1 megaplasmid related to nicotine catabolism, stress induced by nicotine degradation and biotechnological applications..



- using 3D printing for creating teaching materials to support molecular bioscience education.



## Latest paper:

El-Sabeh et al. BMC Genomics (2023) 24:516  
<https://doi.org/10.1186/s12864-023-09644-3>

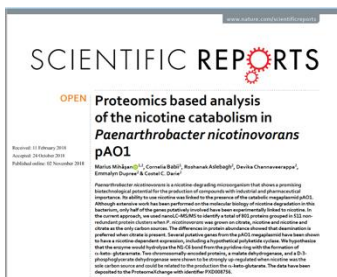
BMC Genomics

Open Access

Characterisation of the *Paenarthrobacter nicotinovorans* ATCC 49919 genome and identification of several strains harbouring a highly syntenic *nic*-genes cluster

Amada El-Sabeh<sup>1</sup>, Andreea-Mihaela Miesnita<sup>1</sup>, Iustin-Tiberiu Munteanu<sup>1</sup>, Iasmina Honceriu<sup>1</sup>, Fakhri Kallabi<sup>1,2</sup>, Razvan-Stefan Boiangiu<sup>1</sup> and Marius Mihasan<sup>1\*</sup>

## Most Important paper:



Received: 23 July 2020 | Revised: 4 January 2021 | Accepted: 17 February 2021  
DOI: 10.1002/bmb.21493

ARTICLE

WILEY

### A beginner's guideline for low-cost 3D printing of macromolecules usable for teaching and demonstration

Marius Mihasan<sup>1</sup>

BioActive Research Group, Laboratory of Biochemistry and Molecular Biology, Faculty of Biology, "Alexandru Ioan Cuza" University of Iasi, Iasi, Romania

Correspondence

Marius Mihasan, BioActive Research Group, Laboratory of Biochemistry and Molecular Biology, Faculty of Biology, "Alexandru Ioan Cuza" University of Iasi, Iasi, Romania. Email: marius.mihasan@uaic.ro

Abstract

The structure and function of biomolecules relationship is the hallmark of biochemistry, molecular biology, and life sciences in general. Physical models of macromolecules give students the possibility to manipulate these structures in three dimensions, developing a sense of spatiality and a better understanding of key aspects such as atom size and shape, bond lengths and symmetry. Several molecular model systems were developed specifically to represent particular classes or groups of molecules and hence lack the flexibility of a universal solution. Three-dimensional printing could nevertheless provide such a universal solution, as it can be used to create physical models of biomolecular structures based on the teacher's or demonstrator's needs and requirements. Here, insulin was used as a model molecule and several depiction and printing parameters were tested in order to highlight the technical limitations of the approach. In the end, a set of settings that worked is provided which could serve as a starting point for anyone wishing to print his or her own custom macromolecular model on the cheap.

KEYWORDS

3D printing; general public; insulin; molecular models

## Developed educational resources:



<https://www.nature.com/articles/s41598-018-34687-y>

<https://doi.org/10.1002/bmb.21493>

<https://modele-moleculare.ro/>

# Understanding Life Sciences relies on understanding Structural Biology

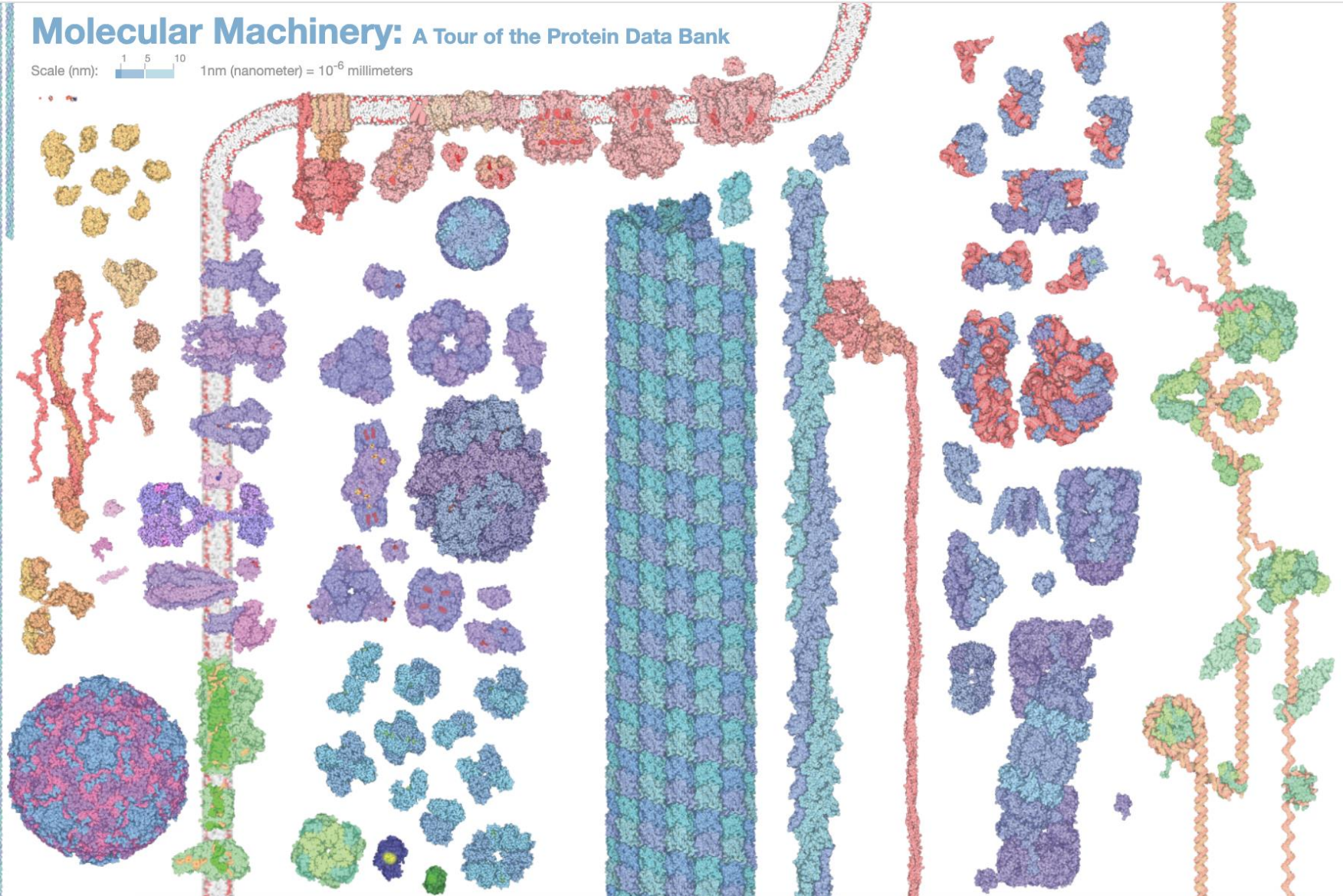


ALEXANDRU IOAN CUZA UNIVERSITY of IAȘI

www.uaic.ro

## Molecular Machinery: A Tour of the Protein Data Bank

Scale (nm): 1 5 10 1nm (nanometer) = 10<sup>-6</sup> millimeters



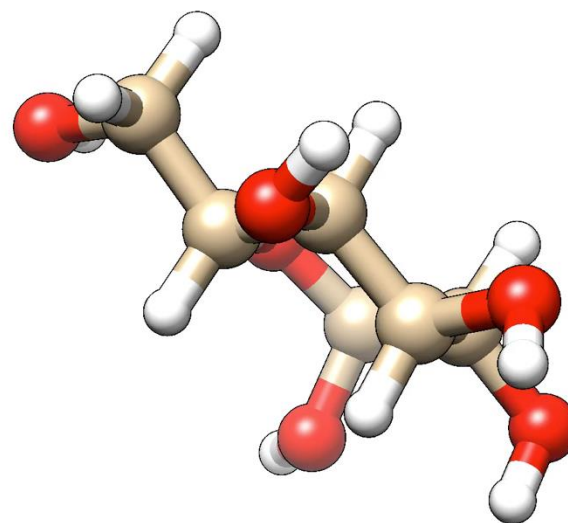
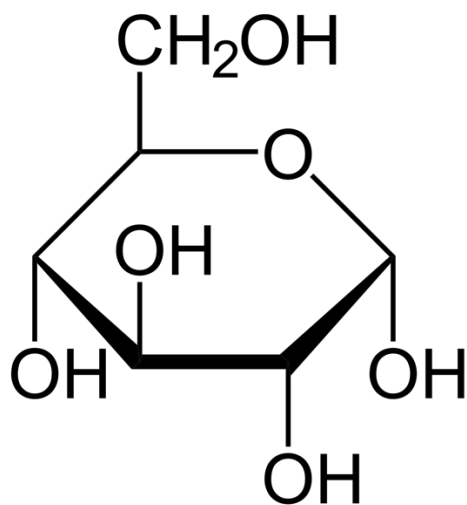
Extracellular

Membrane

Intracellular/Cytosol

Slide 3 / 4  
Intracellular/Nucleus

<https://cdn.rcsb.org/pdb101/molecular-machinery/>



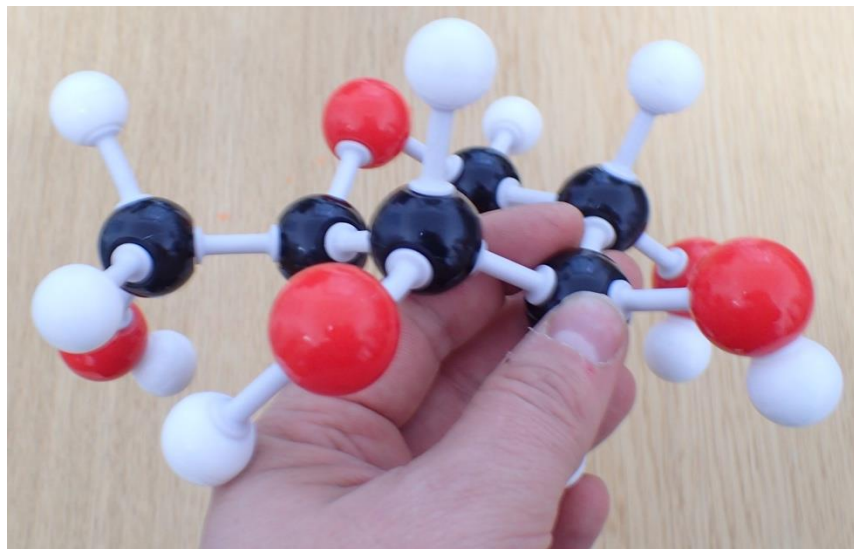
$\alpha$ -D-glucopyranose

# Molecular models to aid teaching - Molymod



ALEXANDRU IOAN CUZA UNIVERSITY of IAȘI

www.uaic.ro



[http://www.molymod.com/MMS-004\\_Inorganic\\_\\_Organic\\_Teacher\\_Set.jpg](http://www.molymod.com/MMS-004_Inorganic__Organic_Teacher_Set.jpg)

**molymod<sup>®</sup>**

The *original* dual-scale system of molecular models

# Custom macromolecular models for teaching are need it



The **custom macromolecular models** should be:

Based on real scientific data;

Depicted using standardized representations;

Easy to edit and adapt to the outcomes of a specific lesson;

Cheap to fabricate and reproduce;

Easy to distribute

224 572

structures

1 068 577 CSM  
freely available

molecular visualization software

Chimera, PyMol

3D printing can do that

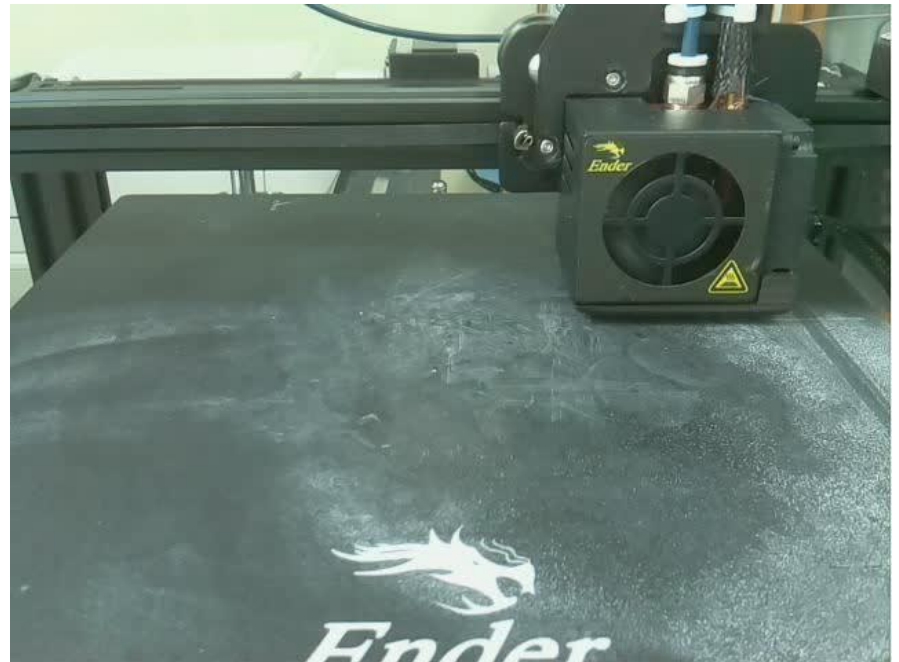
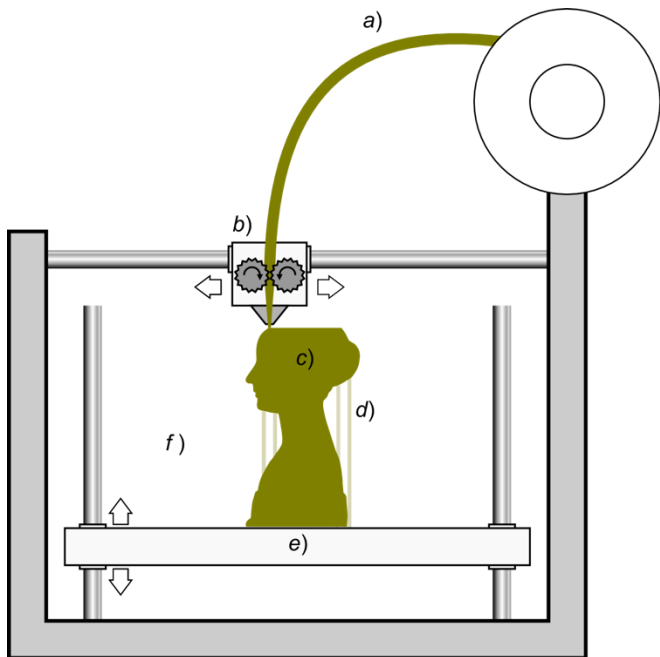


# What is 3D printing?



**3D printing** - construction of a three-dimensional object from a digital 3D model.  
Also termed **additive manufacturing**.

Material extrusion / Fused filament fabrication (FFF) / fused deposition modeling (FDM)



Scopigno R et al. (2017). "Digital Fabrication Techniques for Cultural Heritage: A Survey". Computer Graphics Forum 36 (1): 6-21

# Steps involving fabricating a macromolecular model



Download structure from



PDB or CIF file

Visualize and prepare the model in

UCSF Chimera

STL file

Prepare the file for printing using

Ultimaker Cura

GCODE file

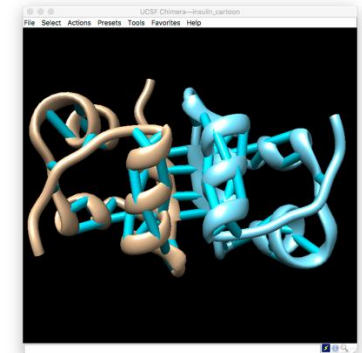
Print

22.10.2024



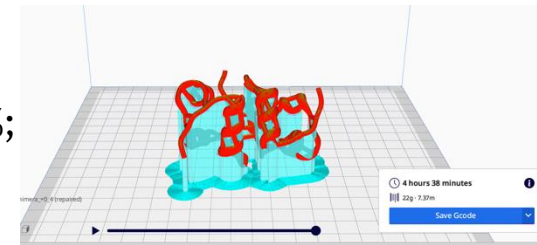
3D printed macromolecular models

1. Chose or combine **visualization styles**;
2. Add **H bonds** or **create struts** to make the model more sturdy (mandatory for cartoon and balls and sticks models, not required for surface);
3. Increase the **thickness** of each printed element and/or **improve the smoothness** for molecular surfaces.



## A. Generate the computer model

1. Set the printing scale;
2. **Orient** the model on printing bed;
3. Set printing **resolution**;
4. Set shell **wall thickness** and **infill %**;
5. Automatically **add support**;
6. **Slice** the model;
7. **Send** the resulting gcode to printer (via SD-Card, USB or WiFi)



## B. Print the model

Support material removal



## C. Clean up and finalize the physical model





**jove** Journal of Visualized Experiments

www.jove.com

## Video Article 3D Printing of Biomolecular Models for Research and Pedagogy

Eduardo Da Veiga Beltrame<sup>1</sup>, James Tyrwhitt-Drake<sup>2</sup>, Ian Roy<sup>3</sup>, Raed Shalaby<sup>4</sup>, Jakob Suckale<sup>4</sup>, Daniel Pomeranz Krummel<sup>5</sup>

<sup>1</sup>Department of Physics, Brandeis University

<sup>2</sup>Bioinformatics and Computational Biosciences Branch (BCBB), NIH/NIAD/OD/OSSMO/OCICB

<sup>3</sup>Library/LTS/MakerLab, Brandeis University

<sup>4</sup>Interfaculty Institute of Biochemistry (IFIB), University of Tübingen

<sup>5</sup>Winship Cancer Institute, Emory University School of Medicine

Correspondence to: Jakob Suckale at [jakob.suckale@uni-tuebingen.de](mailto:jakob.suckale@uni-tuebingen.de), Daniel Pomeranz Krummel at [dapk@brandeis.edu](mailto:dapk@brandeis.edu)

URL: <https://www.jove.com/video/55427>

DOI: [doi:10.3791/55427](https://doi.org/10.3791/55427)

Keywords: Engineering, Issue 121, 3D printing, molecular biology, education, structure, biomolecules, models, extrusion printers

Date Published: 3/13/2017

Citation: Da Veiga Beltrame, E., Tyrwhitt-Drake, J., Roy, I., Shalaby, R., Suckale, J., Pomeranz Krummel, D. 3D Printing of Biomolecular Models for Research and Pedagogy. *J. Vis. Exp.* (121), e55427, doi:10.3791/55427 (2017).

JOURNAL OF  
**CHEMICAL EDUCATION**

Communication

pubs.acs.org/jchemeduc

## Rapid Access to Multicolor Three-Dimensional Printed Chemistry and Biochemistry Models Using Visualization and Three-Dimensional Printing Software Programs

Ken Van Wieren,<sup>†</sup> Hamel N. Taylor,<sup>‡</sup> Vincent F. Scalfani,<sup>§</sup> and Nabyl Merbouch\*<sup>†‡</sup>

<sup>†</sup>Science Technical Center and <sup>‡</sup>Department of Chemistry, Simon Fraser University 8888 University Drive Burnaby, British Columbia V5A 1S6, Canada

<sup>§</sup>University Libraries, Rodgers Library for Science and Engineering, The University of Alabama, Tuscaloosa, Alabama 35487, United States

Supporting Information

JOURNAL OF  
**CHEMICAL EDUCATION**

Article

pubs.acs.org/jchemeduc

## A Simplified Method for the 3D Printing of Molecular Models for Chemical Education

Oliver A. H. Jones\*<sup>†‡</sup> and Michelle J. S. Spencer\*<sup>†‡</sup>

<sup>†</sup>Australian Centre for Research on Separation Science (ACROSS), School of Science, RMIT University, GPO Box 2476, Melbourne, Victoria 3001, Australia

<sup>‡</sup>School of Science, RMIT University, GPO Box 2476, Melbourne, Victoria 3001, Australia

**Biochemistry and Molecular Biology Education**

Biochemistry and Molecular Biology Education

A beginner's guideline for low-cost 3D printing of macromolecules usable for teaching and demonstration

Marius Mihasan

First published: 23 March 2021 | <https://doi.org/10.1002/bmb.21493>





## Secondary structure of lysozyme

Relevant Chimera model depiction settings\*

	Width	Height
Coil	0.7	0.7
Helix	1.4	0.7
Sheet	1.4	0.7
Arrow (base)	2.8	0.7
Arrow (tip)	0.7	0.7
Nucleic	1	0.7

Number of grid divisions: 10 Erase All  
Changing grid division erases drawn cross section

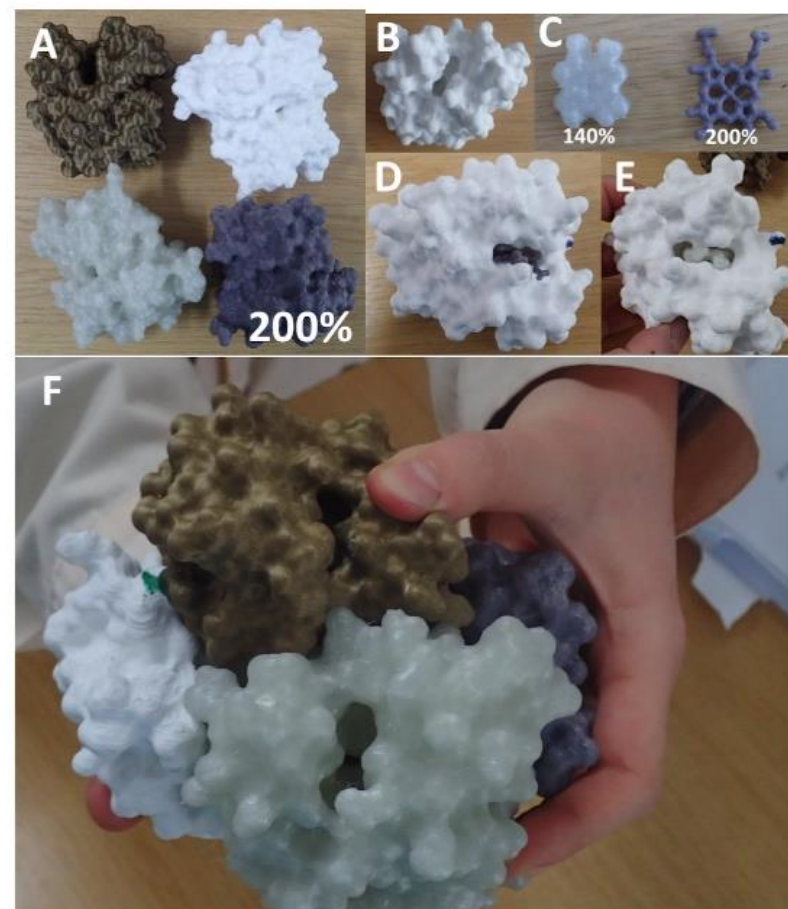
<https://3dprint.nih.gov/discover/3dpx-014894>

Printed scale and physical model



## Quaternary structure of human deoxyhemoglobin

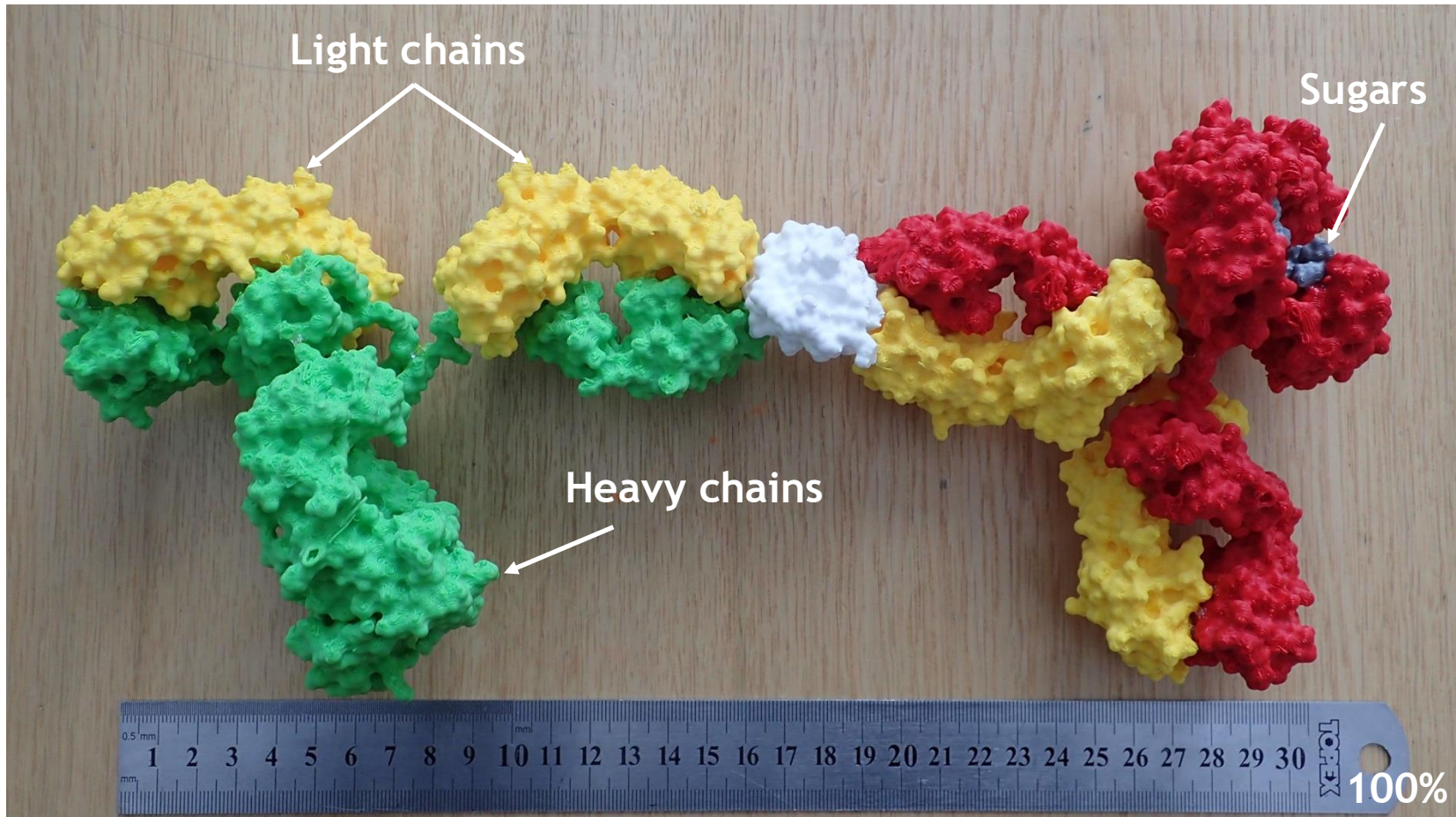
Printed scale and physical models



<https://3dprint.nih.gov/discover/3dpx-014895>



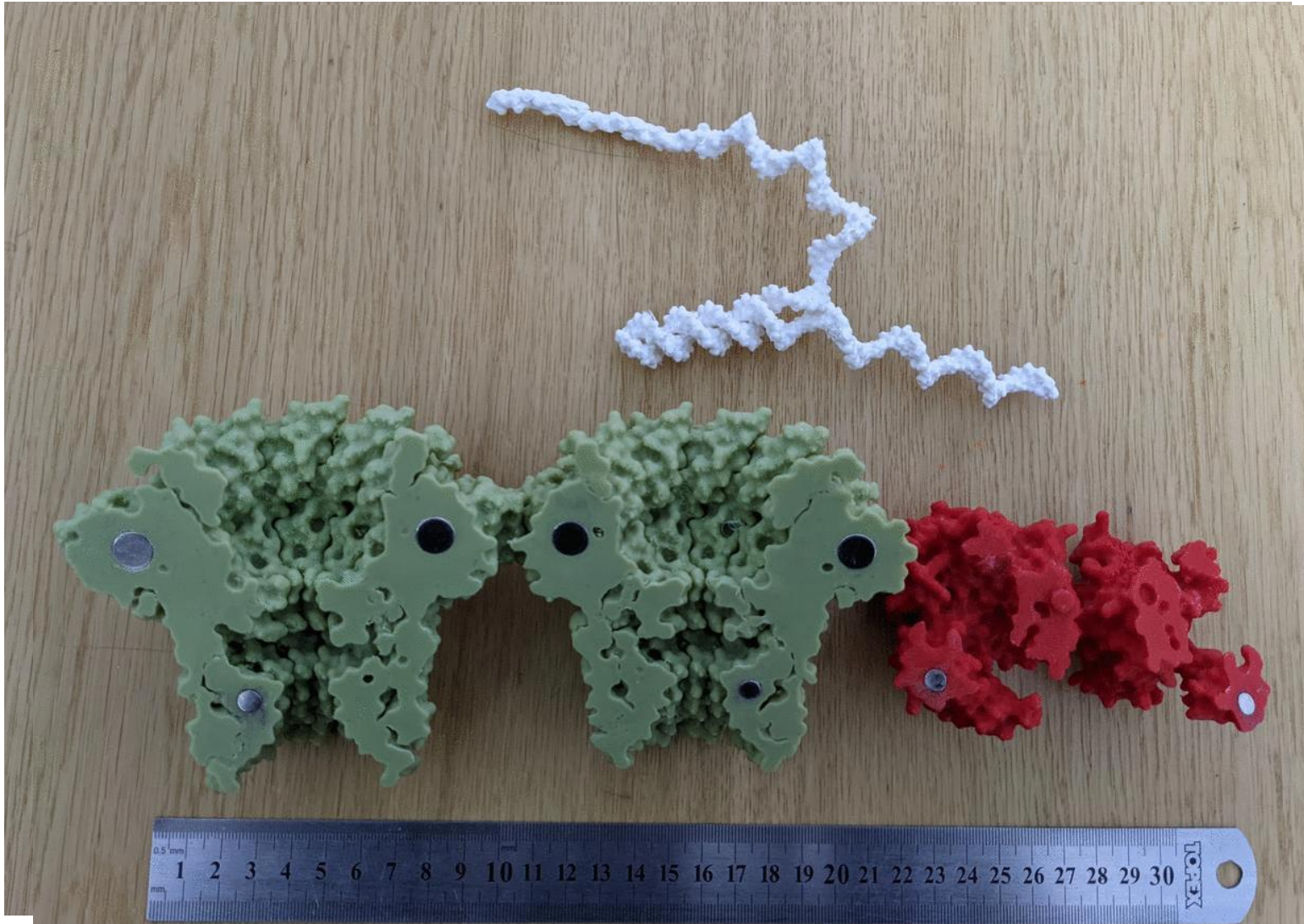
## Antibodies interacting with an antigen (lysozyme)



<https://3dprint.nih.gov/discover/3dpx-015554>



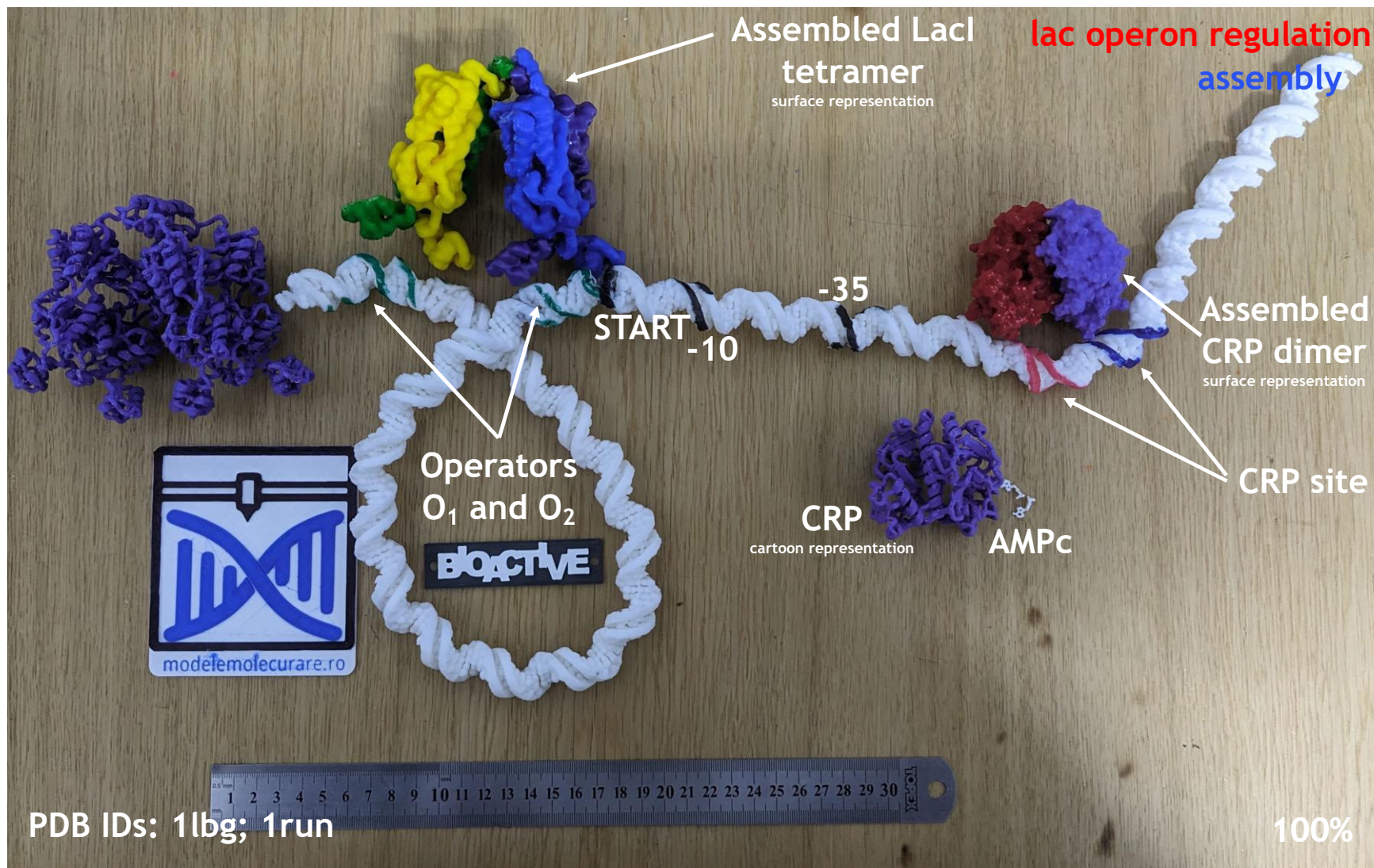
## A protein nanopore sequencing DNA



# Examples of printed models currently used for teaching

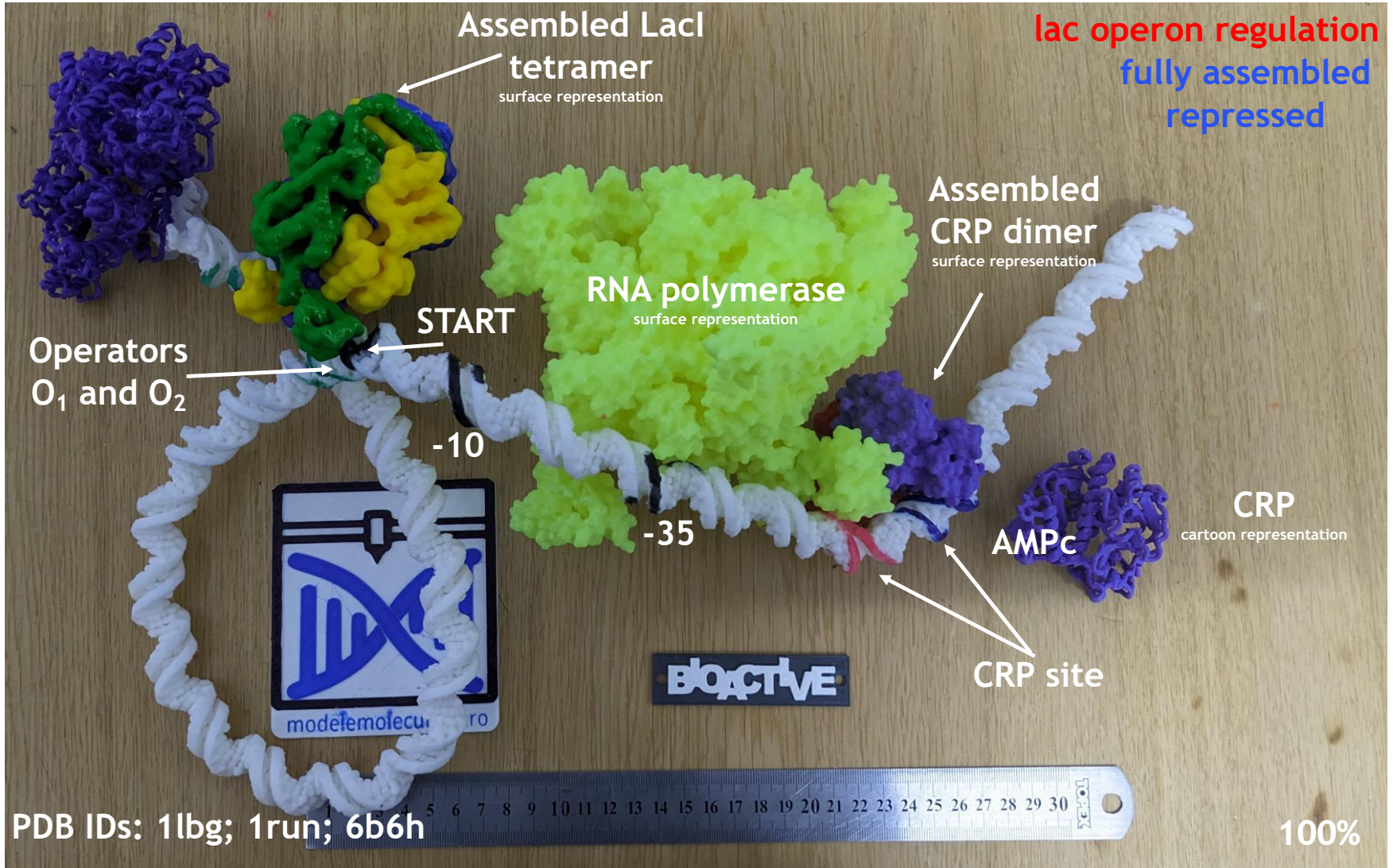


## Physical model for teaching lac operon regulation



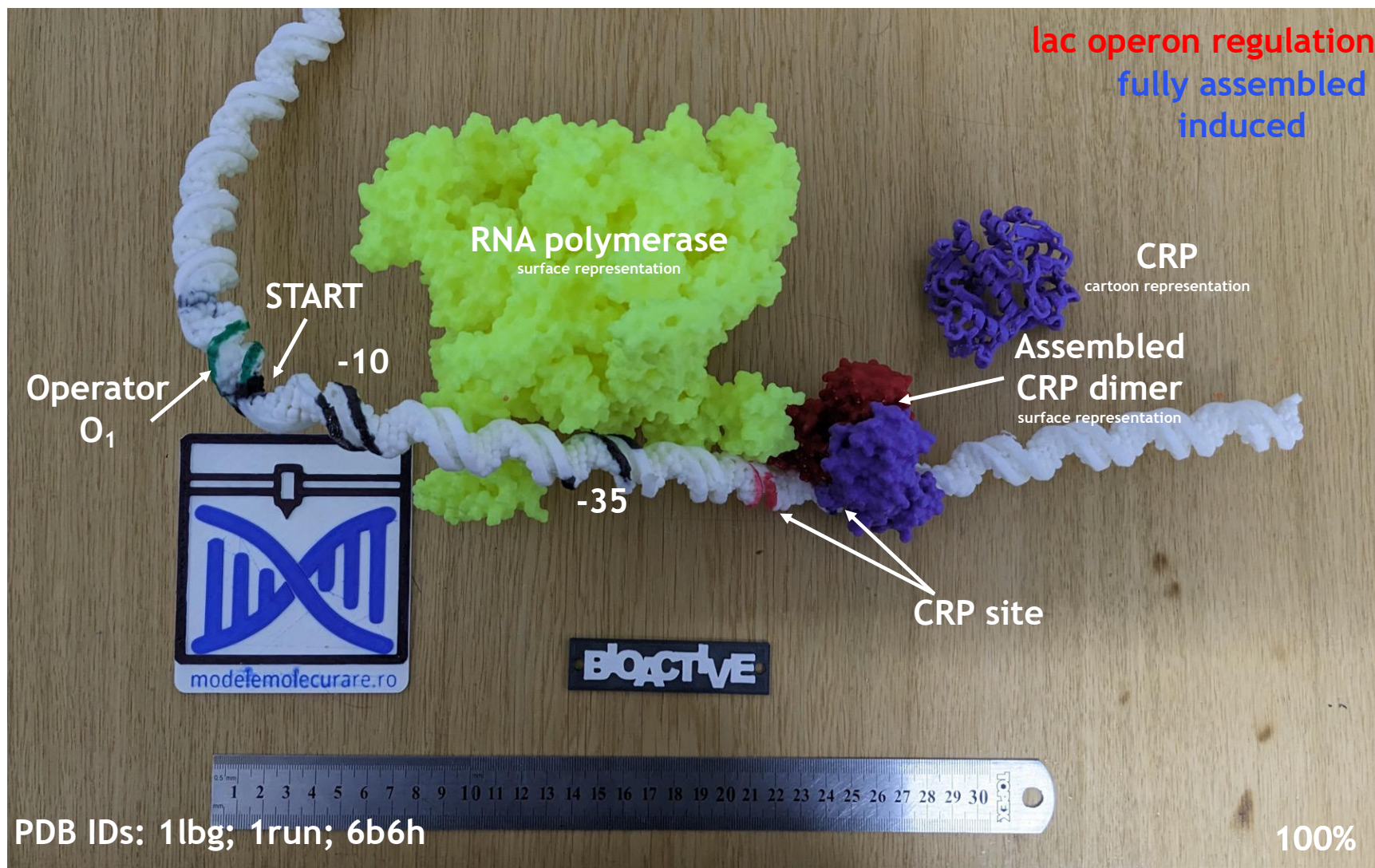


## Physical model for teaching lac operon regulation





## Physical model for teaching lac operon regulation



# Alternative ways of using the models for teaching



## Asking students to paint the models in order to recognize different structures





# But are these models efficient?



## Evaluation of impact is key

Models	NIH 3D DOI:	Assessment questions	Learning objective	Biomolecular visualization learning goals
<b>Amino acids, peptides and proteins</b>				
4 amino acids (L-Glycine, L-Tryptophan, L-Proline, L-Arginine) in different representations	10.60705/3dpx/21049.1	Q2, Q4	Recognize a variety of molecular representations (i.e. stick and space fill).	AR2.02 students will describe the atoms that are represented in different renderings. (novice)
Two insuline chains (PDBID 4ins, chains C and D) in 4 representations: sticks, balls and sticks, cartoon and surface	10.60705/3dpx/21051.1	Q1, Q2, Q3, Q4, Q7	Recognize a variety of molecular representations (i.e. stick and space fill). Identify features of the peptide backbone, including the amino and carboxyl ends, peptide bonds, and alpha carbon. N to C direction	MR1.01 given a rendered structure of a biological polymer students will be able to identify the ends of a biological polymer. (novice, amateur, expert) MR1.02 given a rendered structure, students will be able to divide the polymer into its monomer units. (novice)
Quaternary structure of human deoxihaemoglobin with removable hem	10.60705/3dpx/14895.2	Q10, Q11	Describe why and how protein subunits interact to make the "quaternary structure"	TC2.06 Students can identify the levels of protein structure (e.g., parse a tertiary/quaternary structure into a series of secondary structures/motifs) and the ways in which they are connected from a three-dimensional structure. (Novice, Amateur, Expert)
<b>Nucleotides and nucleic acids</b>				
Deoxyribonucleotides and ribonucleotides in in different representations.	10.60705/3dpx/21050.1	Q2,	Recognize a variety of molecular representations (i.e. stick and space fill).	AR2.02 students will describe the atoms that are represented in different renderings. (novice)
B-DNA dodecamer printed in flexible	10.60705/3dpx/14893.2	Q5	Understand the flexibility of DNA due to the higher number of rotatable bonds.	AG3.01 Students can identify a dihedral/torsion angle in a three-dimensional representation of a macromolecule. (Novice) AG3.02 Students can identify the planes between which a dihedral/torsion angle exists within a three-dimensional representation of a macromolecule. (Novice)

<https://biomolviz.org/>. Biochem Mol Biol Educ. 2017 Jan 2;45(1):69-75. doi: 10.1002/bmb.20991.

# But are these models efficient?



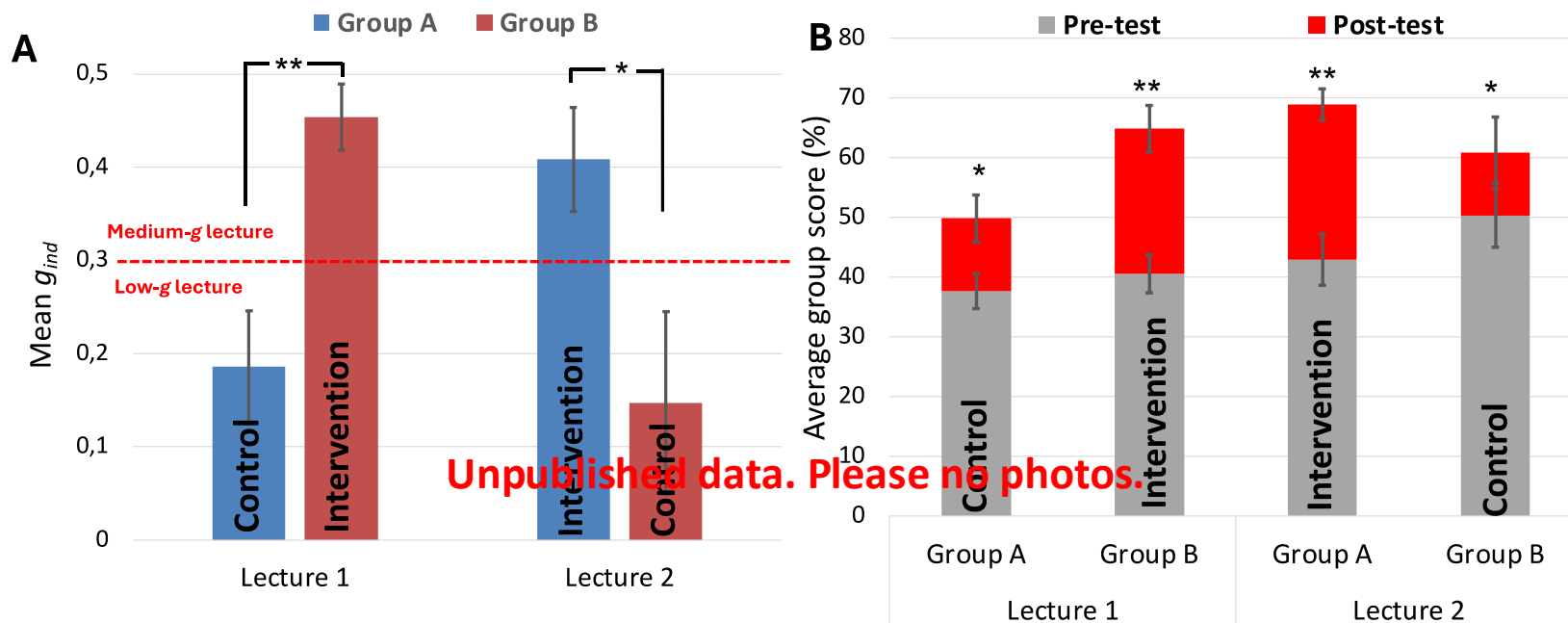
## A compensatory research study

	Week 1	Week 2			Week 3			Week 4 - Week 7
		Pre-test 1	Lecture 1 - Proteins Structure	Post-test 1	Pre-test 2	Lecture 2 - DNA structure	Post-test 2	
Group A	Announcement Recruitment Consent	2 days before lecture, 30 minutes, 13 questions	No intervention	2 days after lecture, 30 minutes, 13 questions	2 days before lecture, 30 minutes, 10 questions	<b>Intervention</b>	2 days after lecture, 30 minutes, 10 questions	Intervention and Feedback form
Group B			<b>Intervention</b>			No intervention		

The project was approved by the ethics committee at the Department of Psychology and Education Sciences, Alexandru Ioan Cuza University of Iași (no 186/29.01.2024). Students were informed prior to the start of instruction of the purpose and objectives of the investigation. Student participation was anonymous and voluntarily, and each student was presented with the opportunity to exclude him/herself from the study at any time. Information regarding data security, the type of information obtained, data storage procedures, and the measures taken to protect participants' anonymity was provided. Furthermore, students were assured that participation would have no bearing on any score assignment and that the results could be used for publication.



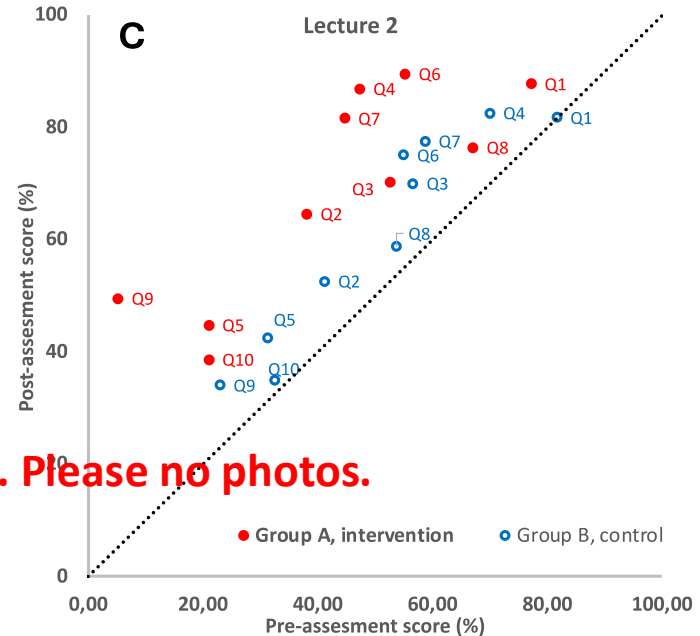
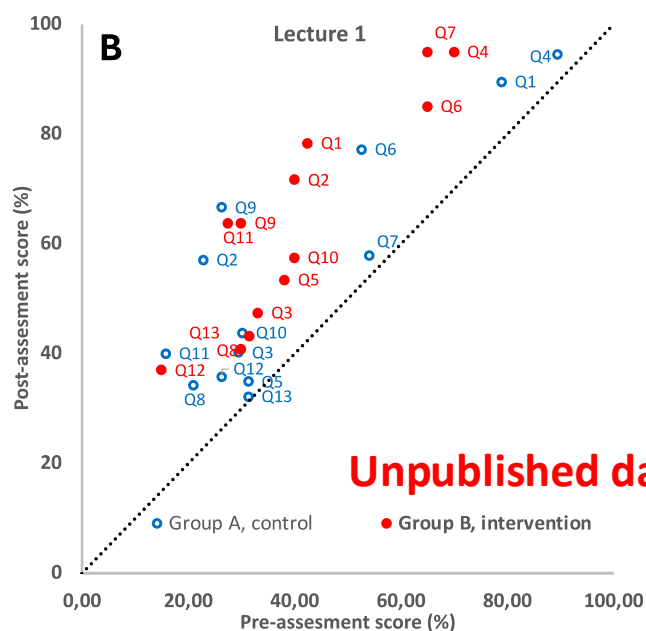
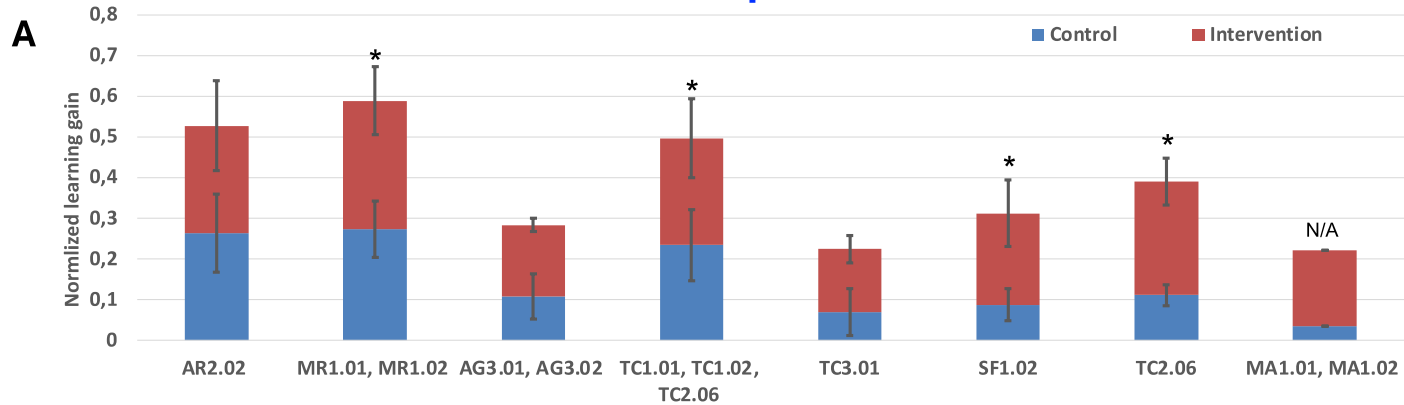
## Individual learning gain



Boiangiu RS, Popa LN, Mihasan M. *Journal of Science Education and Technology*, submitted manuscript



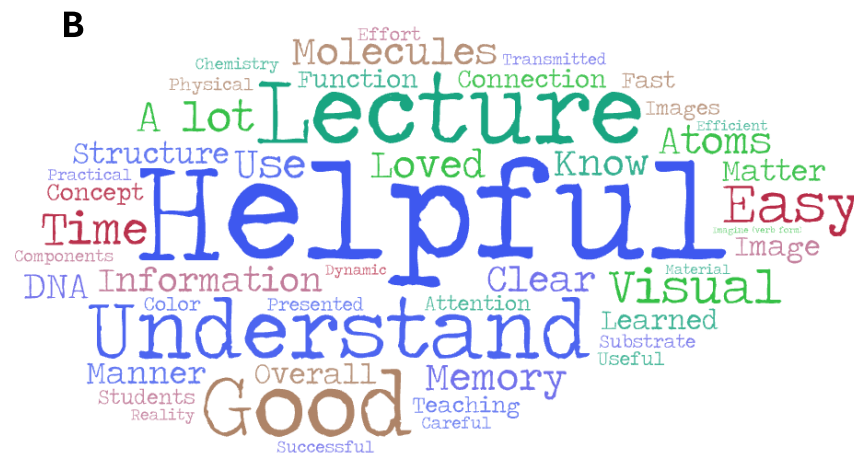
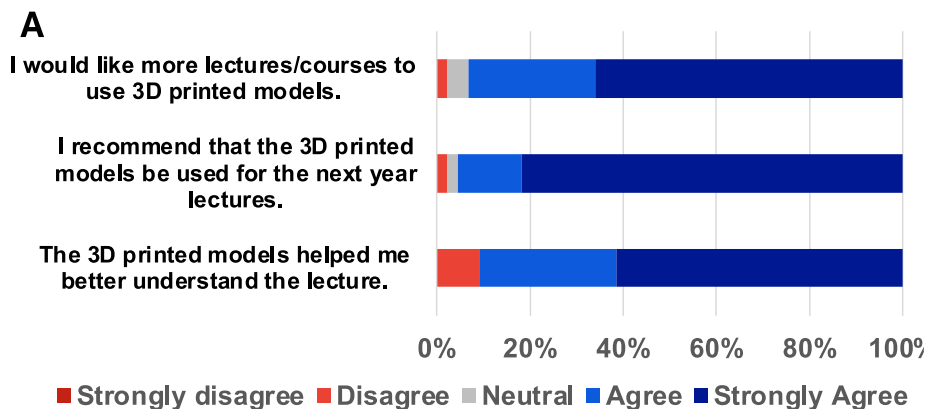
## Individual questions



**Unpublished data. Please no photos.**



## Free-form assessment



**Unpublished data. Please no photos.**

Boiangiu RS, Popa LN, Mihasan M. *Journal of Science Education and Technology*, submitted manuscript

“The 3D models were **very useful** as the **information and images were transformed into something physical that I could touch**. And this helped me better understand the content presented. **It is easier to understand a notion or a concept if one can hold it in its hand and turn it around to evaluated it from all the angles**”.

# Summary



Usage of physical **models of (macro)molecules improves learning outcomes**, but need to be tailored to teachers needs

**3D printing** offers a cheap way of fabricating and distributing molecular models applicable in low income countries

**Workflows** for printing macromolecular models from PDB **are available** and are based on free software

Models were received by students as being helpful as it provided a hands-on advantage. **Allowing students 3-5 minutes to handle models converted a low-g lecture into a medium-g lecture.**

# Updates and new printed models



ALEXANDRU IOAN CUZA UNIVERSITY of IAȘI

www.uaic.ro

The screenshot shows a Facebook profile page for the group "Identification and Characterization of Biological Active Molecules". The profile picture is a circular image of various fruits. The cover photo is a blurred image of a laboratory setting. The page includes a "Contact Us" button, a "Liked" button, a "Message" button, and a search icon. The "About" section features a map of Iași, Romania, and two paragraphs of text describing the group's location and members. It also shows that 513 people like the page and 521 people follow it. A "PINNED POST" is visible, dated March 9 at 2:09 PM, with a title "Identification and Characterization of Biological Active Molecules". The post text discusses 3D printing of antibody models and provides links to instructions and PDB files. Below the text is a photograph of several colorful 3D printed antibody models in shades of green, yellow, red, and white.

Find us on Facebook @BioActive.bio.uaic.ro

Event coming soon. Few places still available.



ALEXANDRU IOAN CUZA UNIVERSITY of IAȘI

www.uaic.ro

**Promoting visual literacy in bio-molecular sciences education**

September 24, 2024  
Carol Davila University of Medicine and Pharmacy, Bucharest, Romania

Event organised with support from the FEBS Education and Training Committee

Created in **BioRender.com** **bio**

<https://srbbm.biochim.ro/event/promoting-visual-literacy-in-bio-molecular-sciences-education/>

**In person participation recommended, on-line participation possible**

**Interested - drop me an e-mail at: [marius.mihasan@uaic.ro](mailto:marius.mihasan@uaic.ro)**

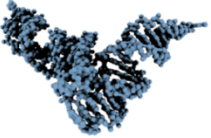
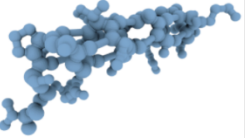
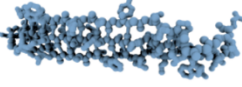
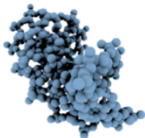
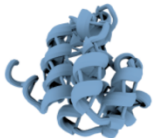




# Most models and instructions on how to print are available under CC BY license



U.S. Department of Health and Human Services — National Institutes of Health

**NIH** NIH 3D Print Exchange

 <p><b>3DPX-014890</b> tRNA in various represent...</p> <p><i>tRNA, teaching</i></p>	 <p><b>3DPX-014891</b> An protein alpha helix in...</p> <p><i>ALFA HELIX, teaching tools</i></p>	 <p><b>3DPX-014892</b> A beta-sheet from a sucro...</p> <p><i>beta-sheet, teaching</i></p>
 <p><b>3DPX-014893</b> B-DNA dodecamer in variou...</p> <p><i>B-DNA, teaching</i></p>	 <p><b>3DPX-014894</b> Cartoon representation of...</p> <p><i>teaching</i></p>	 <p><b>3DPX-014895</b> Quaternary structure of h...</p> <p><i>quaternary complex, teaching tools</i></p>

Submitted by:  **mariusmihasan**

Tue, 2021-03-09 06:48

Remix It Add New Version I Printed This

Printer Technology/Material  
Polylactic Acid (PLA)

Printer Make/Model  
Creality Ender 5 Pro

Print Units mm


Scale At Given Print Units 100x

Pre- and Postprocessing Instructions  
Printed at 0.2 resolution with 2 wall lines and 5% infill. Extensive supports are required but were rather easy to remove. Models are really fragile in the hinge region broke during handling, but were easy to glue back together.

DOWNLOAD

RATING  
Average: 5 (2 votes)

LICENSING  
CC BY



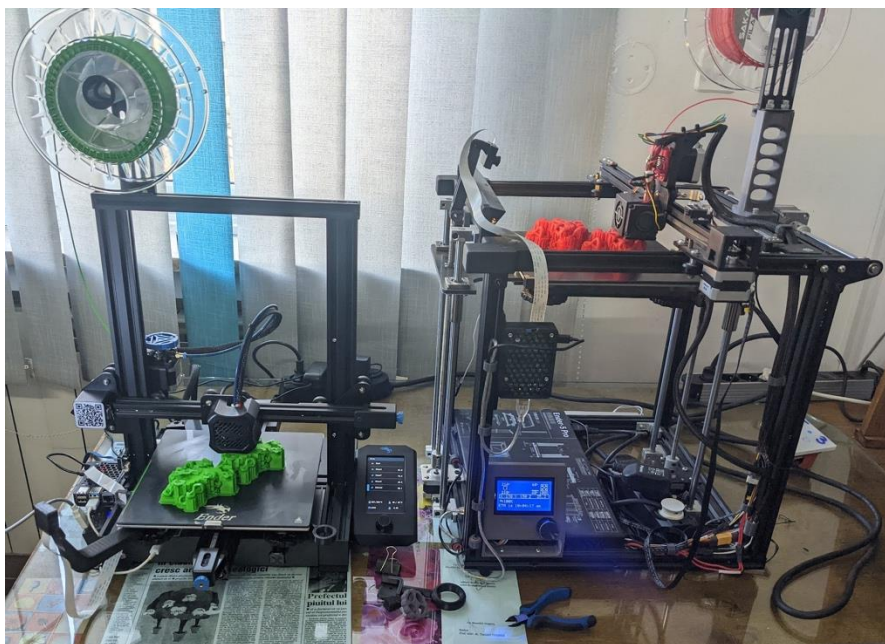
<https://3dprint.nih.gov/users/mariusmihasan/model>

# 3D printing using FFF is accessible



Under 500\$ printers

20\$ - 40\$ Kg of plastic



amazon Deliver to Marius last 700440 All pla Hello, Ma... Returns Account & Orders

All Today's Deals Customer Service Marius's Amazon.com Buy Again Browsing History Gift Cards Amazon's response to COVID-19

1-16 of over 1,000 results for "pla" Sort by: Featured

Department  
3D Printing Supplies  
3D Printing Filament  
Movies & TV  
Movies & Films  
Prime Video  
TV Shows  
See All 6 Departments

Avg. Customer Review  
★★★★★ & Up  
★★★★☆ & Up  
★★★☆☆ & Up  
★★☆☆☆ & Up

Brand  
 HATCHBOX  
 SUNLU  
 OVERTURE  
 TECBEARS  
 3D Solutech  
 MIKASD  
 eSUN  
See more

3D Printing Materials  
 ABS  
 HIPS  
 PETG  
 PLA  
 PVA  
 Wood-Plastic Composite

3D Printer Filament Diameter  
 1.75 mm  
 2.85 mm  
 3.00 mm

3D Printer Filament Weight  
 Up to 499 g  
 500 to 999 g  
 1 to 1.9 kg  
 2 kg & above

From Our Brands  
 Our Brands

Packaging Option  
 Frustration-Free Packaging

Sponsored  
TECBEARS PLA 3D Printer Filament 1.75mm Black, Dimensional Accuracy +/- 0.02 mm, 1 Kg Spool, Pack of 1  
★★★★★ ~ 4,769  
\$19<sup>99</sup>  
Save more with Subscribe & Save  
Ships to Romania

Sponsored  
OVERTURE PLA Filament 1.75mm with 3D Build Surface 200mm x 200mm 3D Printer Consumables, 1kg Spool...  
★★★★★ ~ 6,128  
\$20<sup>99</sup> (\$1.05/10 Items)  
Save more with Subscribe & Save  
Ships to Romania

Best Seller  
HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Black, Pack...  
★★★★★ ~ 11,192  
\$22<sup>99</sup>  
Ships to Romania  
More Buying Choices  
\$21.50 (9 used & new offers)

OVERTURE PLA Filament 1.75mm with 3D Build Surface 200mm x 200mm 3D Printer Consumables, 1kg Spool...  
★★★★★ ~ 6,129  
\$22<sup>99</sup> (\$1.15/10 Items) \$25-99  
Save more with Subscribe & Save  
Ships to Romania  
More Buying Choices  
\$18.99 (17 new offers)

3D printing can be used in high schools/universities from low-income countries to fabricate macromolecular models adapted to teachers needs