Establishing School-based Student Talent Pool: The Story of Building a 3D Bioprinter from Scratch

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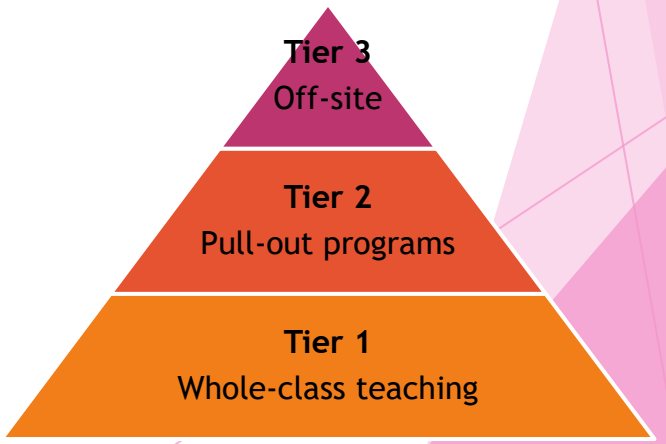
Our School

Science Gifted Education Program

- With Through-train Primary School
  - P.4 and P.5 Science Summer Camp
  - P.6 Budding Scientists Program
  - P.6-S.1 LHT-LFC Joint School Young Scientists Conference
- Pull-out
  - **S.1 Budding Scientists Program**
  - **S.2 Budding Scientists Program**
  - **S.3 Budding Scientists Program**
  - Science Club
  - Bioprinting Club
  - Chemistry Club
  - Neuroscience Club
  - Physics Club
- Off-site
  - Inter-school Science Competitions
  - International Neuroscience Conference
  - iGEM
- For all students
  - S.1-S.3 Biotechnology Curriculum
  - Implementation of new pedagogies developed in Pull-out programs



School-Based Pull-out
Science Gifted Education Program:
Budding Scientists (S1-S3)

Why do we have **Pull-out Programs?**

- Cater **learning diversity**
- Arouse further interest in science
- Equip more-able students with **scientific inquiry skills**

- **Limited by lesson time**

Our Goals

- Build up a **student talent pool** (science/STEAM)
  - Join competitions
  - Lead student helpers in various school activities
- Establish **new pedagogies**, **experiments**
  - Smaller-scale, more efficient
  - To complement the curriculum

Scientific Inquiry

Logical Thinking

Nature of Science

Selection Criteria

1. Top 20 in Integrated Science exam, or nominated by Science teachers
2. Passed our interview which assesses students' scientific communication ability

Characteristics of these students:

- **Intrinsically motivated** in science
- Demonstrate outstanding **scientific literacy**
- Demonstrate **self-learning** ability
- Interested in joining science-related activities

2022 / 23 Curriculum Framework

	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5	Lesson 6
S1	**NOS** • NASA space challenge	**Logic** • Inductive and Deductive Reasoning • Investigative study of heat transfer	**Explanation-driven Inquiry** • Three candles (long, medium, short • Investigate which one will go out first	**Interesting Expt.** • 3D printing	**Investigative Study** • Design an air-cushion which can hold the most number of cotton candy in a free-falling basket	
S2	**NOS** • Perspectives • Using evidence to draw conclusion	**Logic** • Bias • Misuse of statistics	**Explanation-driven Inquiry** • Burning candle covered in inverted gas jar with water below • Investigate why water will be drawn into the gas jar	**Interesting Expt.** • Mini-rocket	**Investigative Study** • Use simple Mathematics and Physics to estimate the height of the school	
S3	**NOS** • Mystery Tube	**Logic** • Logical fallacies	**Explanation-driven Inquiry** • Gas pressure	**Interesting Expt.** • Simplified electrolysis	**Investigative Study** • Investigate the factors affecting the growth of Brine shrimp	

2022 / 23 Curriculum Framework

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Lesson 1: Nature of Science (NOS)

- Let students further ponder about
  - "What is science?"
  - "How to become a good scientist?"

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S3	NOS • Mystery Tube	**Logic** • Logical fallacies	Explanation-driven Inquiry • Gas pressure	Interesting Expt. • Simplified electrolysis	Investigative Study • Investigate the factors affecting the growth of Brine shrimp	

Lesson 2: Logic

- Enhance students' logical thinking by teaching terminologies and concrete examples

2022 / 23 Curriculum Framework

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S3	NOS • Mystery Tube	Logic • Logical fallacies	**Explanation-driven Inquiry** • Gas pressure	Interesting Expt. • Simplified electrolysis	Investigative Study • Investigate the factors affecting the growth of Brine shrimp	

Lesson 3: Explanation-driven Inquiry

- Predict – Observe – Explain (POE)
- Claim – Evidence – Reasoning (CER)
- Focus on how students propose, revise and evaluate their scientific explanation

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Lesson 4: Interesting Experiment

- Eye-opening
- Out-of-syllabus
- Assess students' hands-on skills

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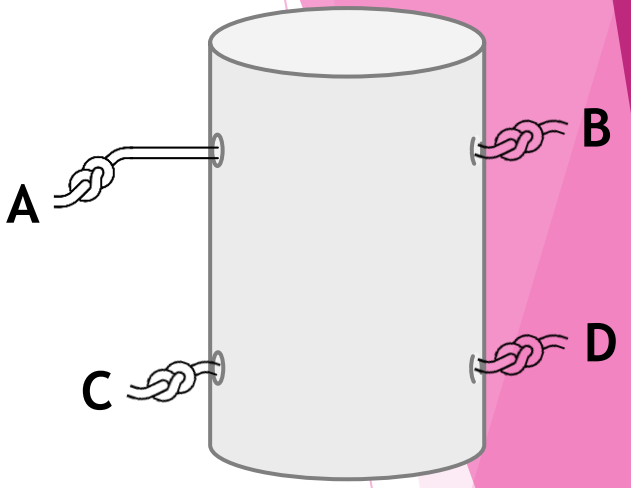
Lesson 5-6: Investigative Study

- Lesson 5: Pre-lab, brainstorming
- Lesson 6: Experiment time!
- Let students to demonstrate what they have learnt in previous lessons (generic skills)

NOS: Mystery Tube (S3)



1. **Observation:** Movement of string pieces when one being pulled
2. **Hypothesis:** How are the string pieces connected inside?
3. **Modelling:** Build a model using transparent plastic cups
4. **Testification:** Test their own model and check if it matches the observation
5. **Modification:** Modify their model when necessary
6. **Conclusion:** Draw conclusion ***(Is the conclusion necessarily correct?)***

Lederman, N., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In the nature of science in science education: Rationales and strategies (pp.83-126). Dordrecht: Springer Netherlands.

NOS: Mystery Tube (S3)

Students can realise:

- Based on the same set of data, **one question might have several answers.**
- **Exploration** and **Explanation** are different.

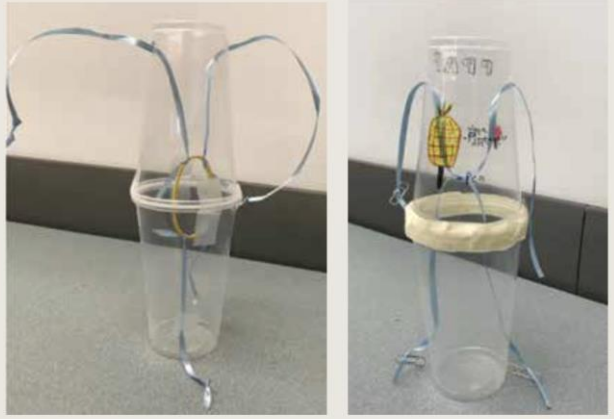
Connecting to the 5-E Inquiry Model

After exploring the five activities, students progressively develop an understanding of argumentation. Table 1 summarizes the purpose and procedure of each activity and the intention of each activity aligned to *NGSS*. Teachers further lead students to think about how argumentation connects with inquiry (the 5-E model: Engage, Explore, Explain, Elaborate, Evaluate). Figure 7 presents the knowledge students should build through each activity and how each activity connects to the 5E inquiry model:

- *Engage:* Students will formulate their questions. Teachers gain the attention of the students and help them formulate the questions.
- *Explore:* This relates directly to the collection of data (exploration) and the evidence (explanation). The teacher allows the students to discover and explore the information and topic for themselves.
- *Explain:* The students are able to make sense of what they observed. The raw data is taken and reasonable inferences are made to construct it into evidence.
- *Elaborate:* Teachers create another activity to expand on the subject and student understanding. It allows students to retest their question in a different format or more in depth. They collect more data and create

FIGURE 6

Students' final models.



Chen, Y.-C., Mineweaser, L., Accetta, D., &Noonan, D. (2018). Connecting argumentation to 5E inquiry for preservice teachers. Journal of College Science Teaching, 47(5), 22-28.

Investigative Study:
Brine Shrimp Investigation (S3)

Investigative Study:
Brine Shrimp Investigation (S3)

Step 1	Step 2	Step 3	Step 4	Step 5
Orientating to the inquiry	**Planning investigation**	**Collecting data**	**Evaluating the data**	**Reflection on the learning**
See-think-wonder	Group discussion	Practical skill	Text for explanation	Gallery walk
Reading to learn	Planning template	Data presentation	Guiding questions	

Formative use of student work
(Selection of best set-up)

Investigative Study: Brine Shrimp Investigation (S3)

Formative use of students' work

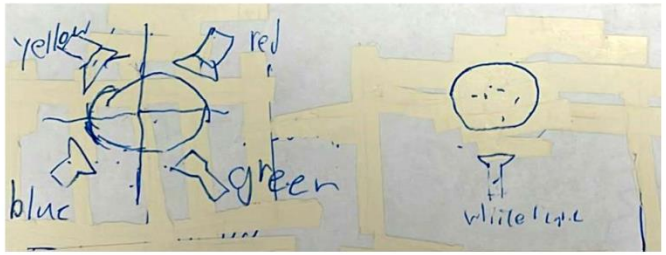
Brine shrimp investigation

What are young brine shrimp larvae's preference for different light colours?

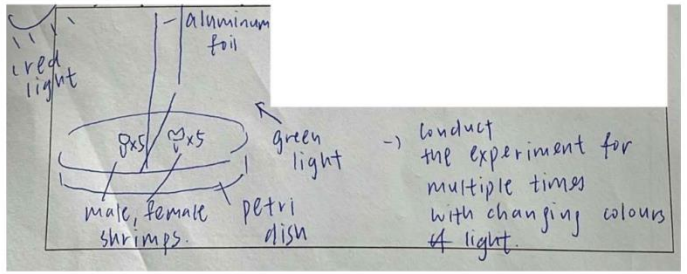
Task 1:

- Examine the following three set-ups:

Set-up A

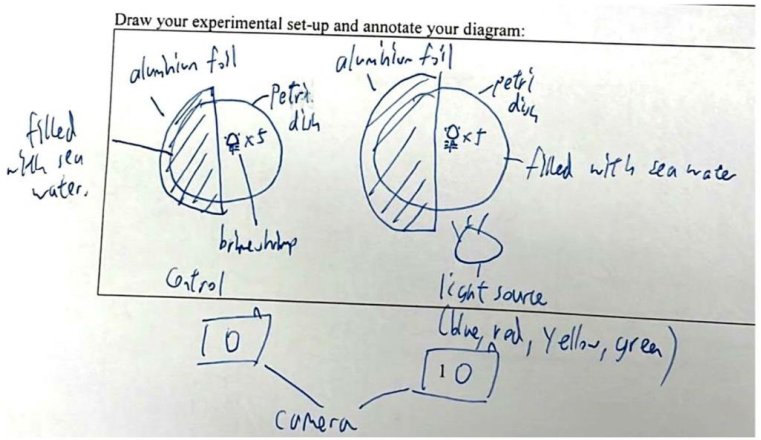


Set-up B



Set-up C

Draw your experimental set-up and annotate your diagram:



(a) Which one of the following set-ups below can generate data that are more accurate and reliable? Why do you think so?

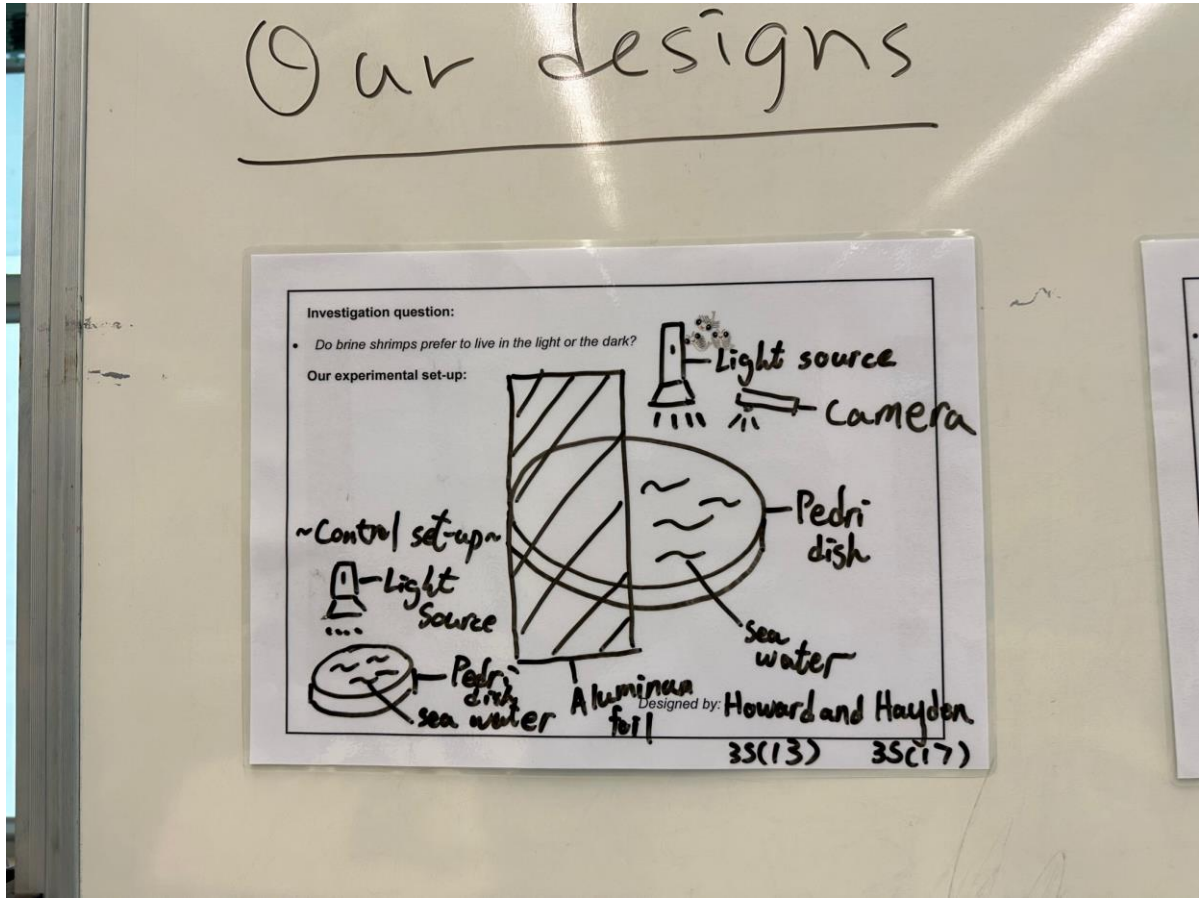
We think that

☐ Set-up A ☐ Set-up B
☐ Set-up C

can produce data that are more accurate and reliable *because*

(b) What else do you think the set-up in (a) can be improved to generate data that are more accurate and reliable? Why do you think so?

Investigative Study:
Brine Shrimp Investigation (S3)



Evaluation on the Effectiveness

- Pre- and post-activities questionnaire
- Interviewing students
- Interpreting students’ works (written, oral responses)

Meet Leo: A Twice Exceptional Learner

- Underperform in Chinese
- Top in Integrated Science
- Self-learner
- Enthusiastic and Intrinsically motivated in learning science
- Interests: 3D printing, aquarium, keeping ants as pet

Levels of Inquiry

	Level 1 Confirmation (Cookbook)	Level 2 Structured	Level 3 Guided	Level 4 Open
Problem	Provided by Teachers	Provided by Teachers	Provided by Teachers	Student-initiated ☺
Procedure	Provided by Teachers	Provided by Teachers	Student-initiated ☺	Student-initiated ☺
Solution	Provided by Teachers	Student-initiated ☺	Student-initiated ☺	Student-initiated ☺

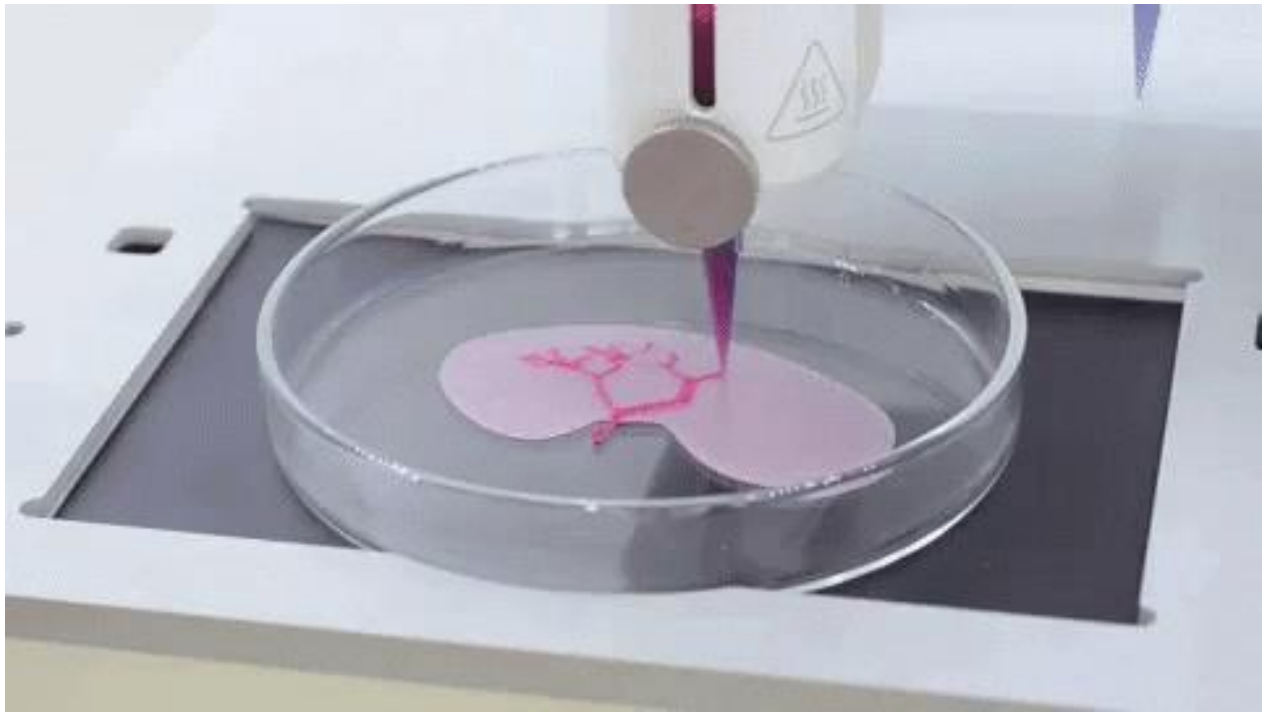
Research Mentorship Programme

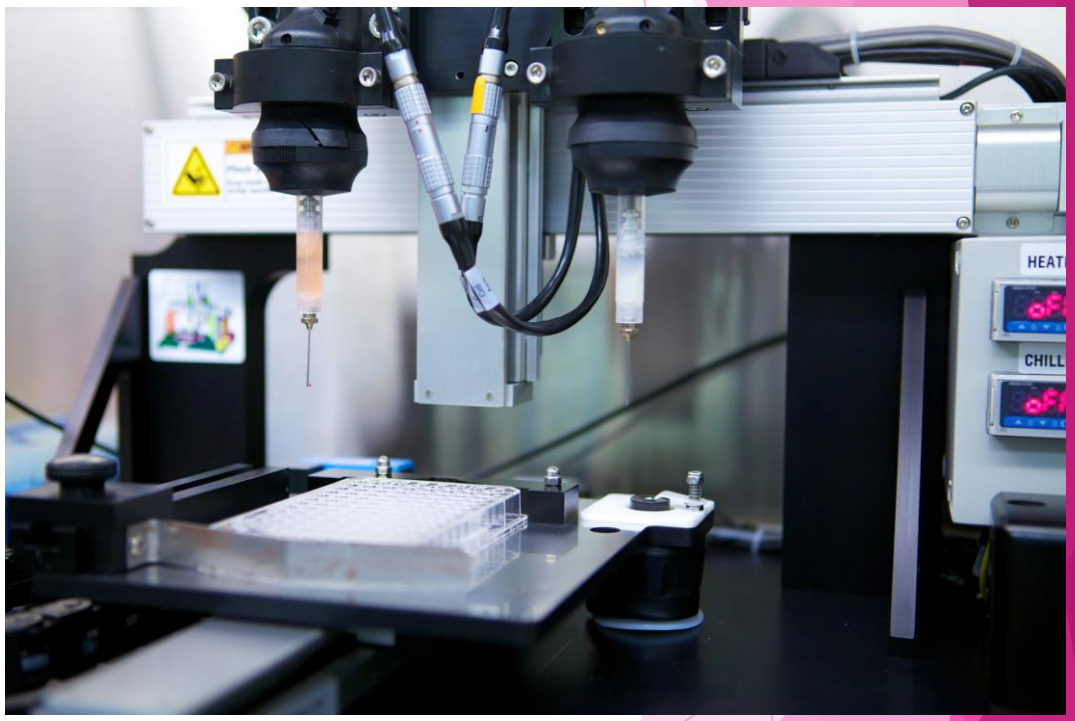
- Open Inquiry
- Authentic Research Experience
- Focus on students’ autonomy
- Empower Students Through Creativity and Choice
- Collaboration with local Universities

Leo's Passion for 3D Printing

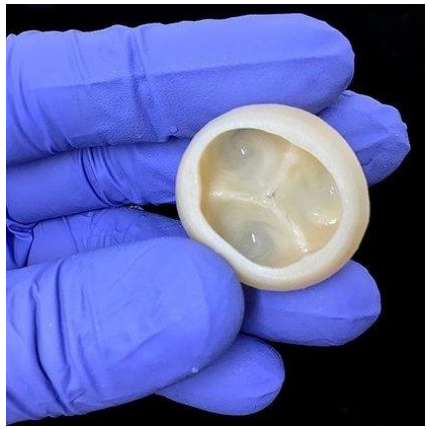
- As a biology teacher, how can I help exploring Leo’s talent?

3D Printing in Biology





Clinical Application of Bioprinting

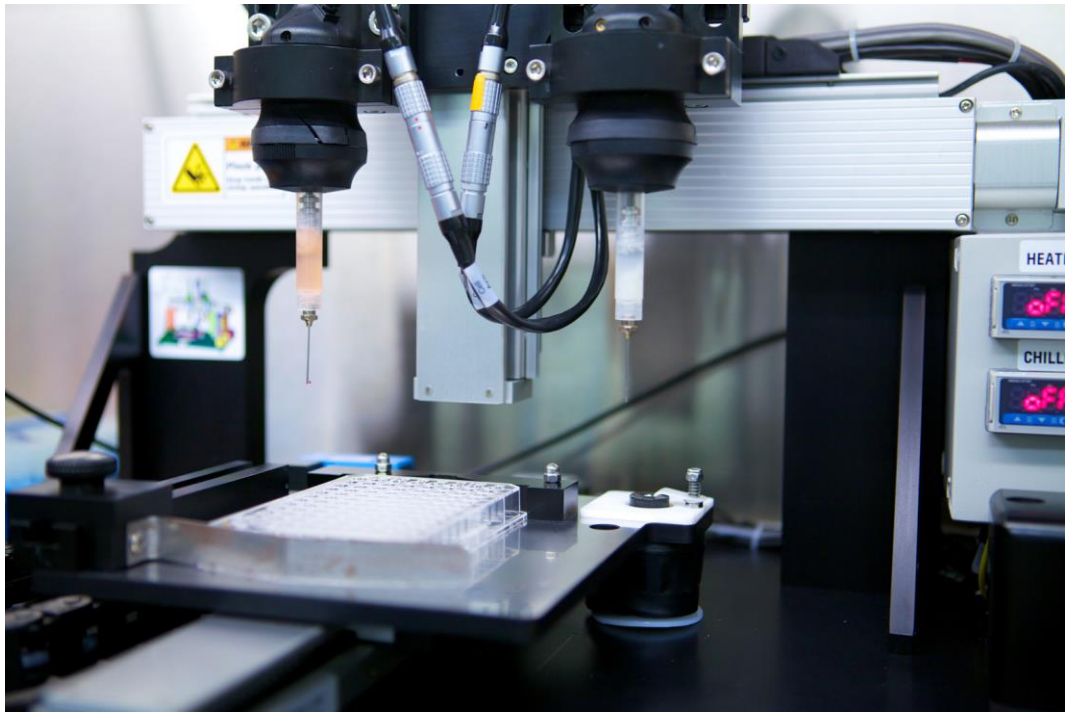


Agarwal S, Saha S, Balla V, Pal A, Barui A, Bodhak S. 2020. Current Developments in 3D Bioprinting for Tissue and Organ Regeneration-A Review. Frontiers in Mechanical Engineering 6:90.

hket
香港經濟日報
利用3D打印
日本科學家製出紋理分明和牛？

解構3D打印植物性三文魚
蘑菇
澱粉/瓊膠
BIO
BIOprinter
豌豆蛋白
將會添加植物性
Omega-3

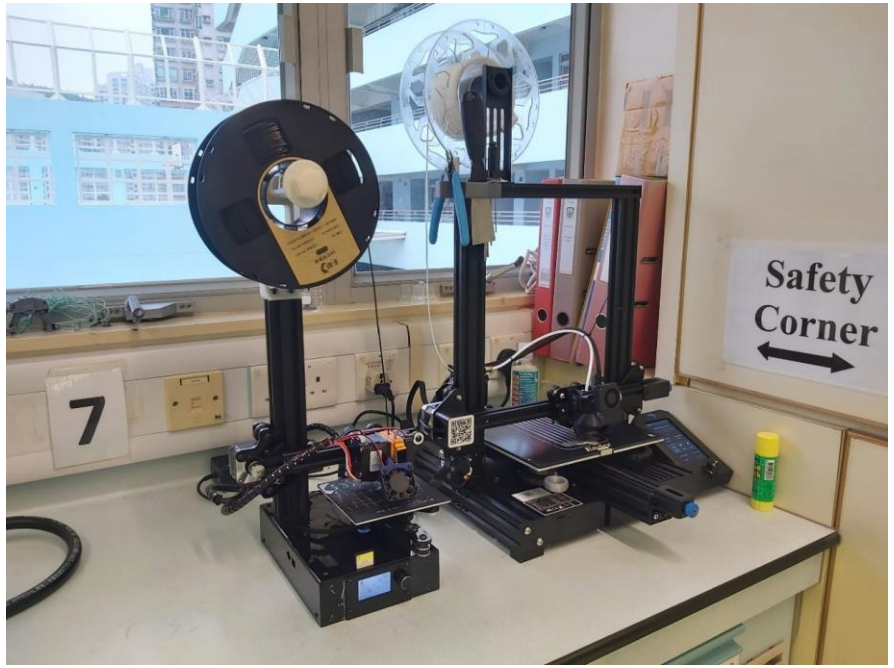
Bioprinting in Secondary School?

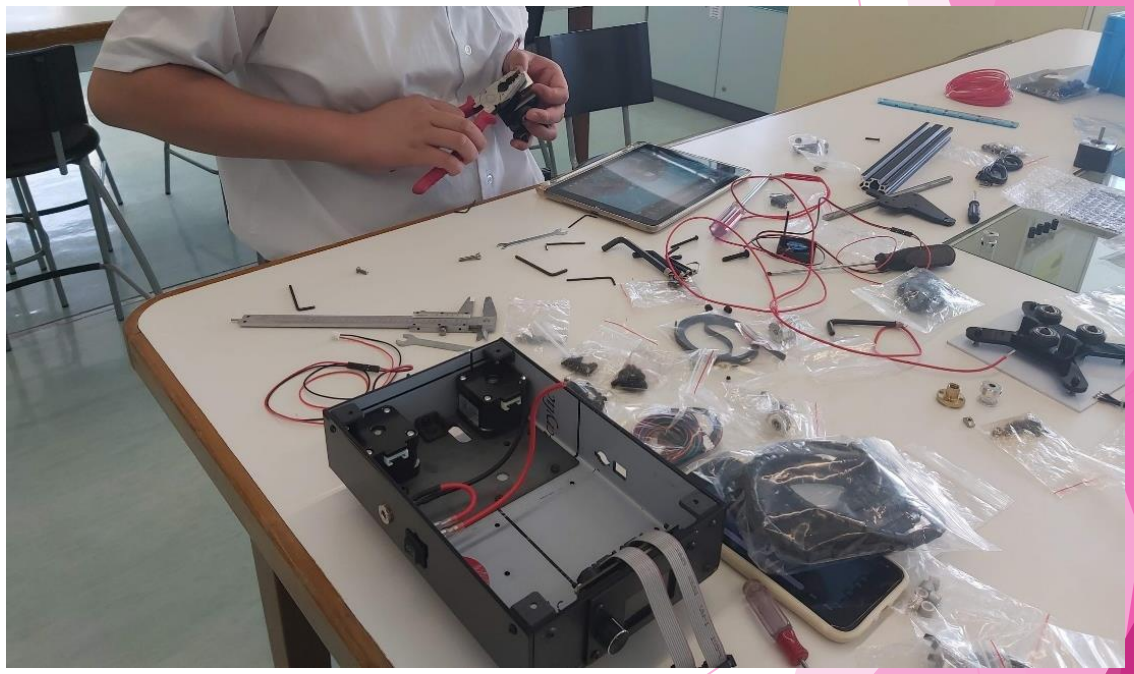


Difficulties:

- Expensive bioprinter (>10K USD)
- Expertise
- Uncommon reagents
- Professional equipment

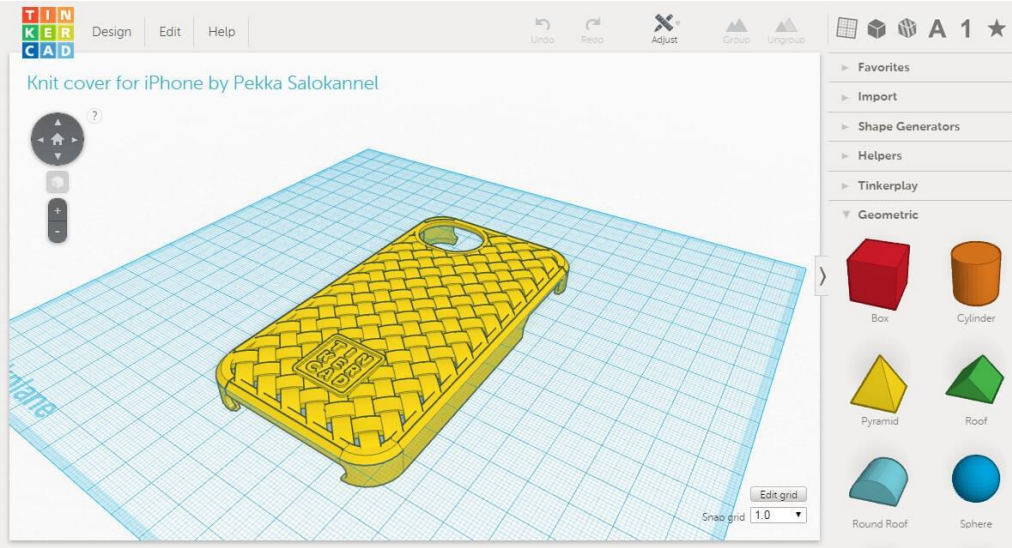
From Curiosity to Innovation:
Modify a commercial 3D printer into bioprinter?



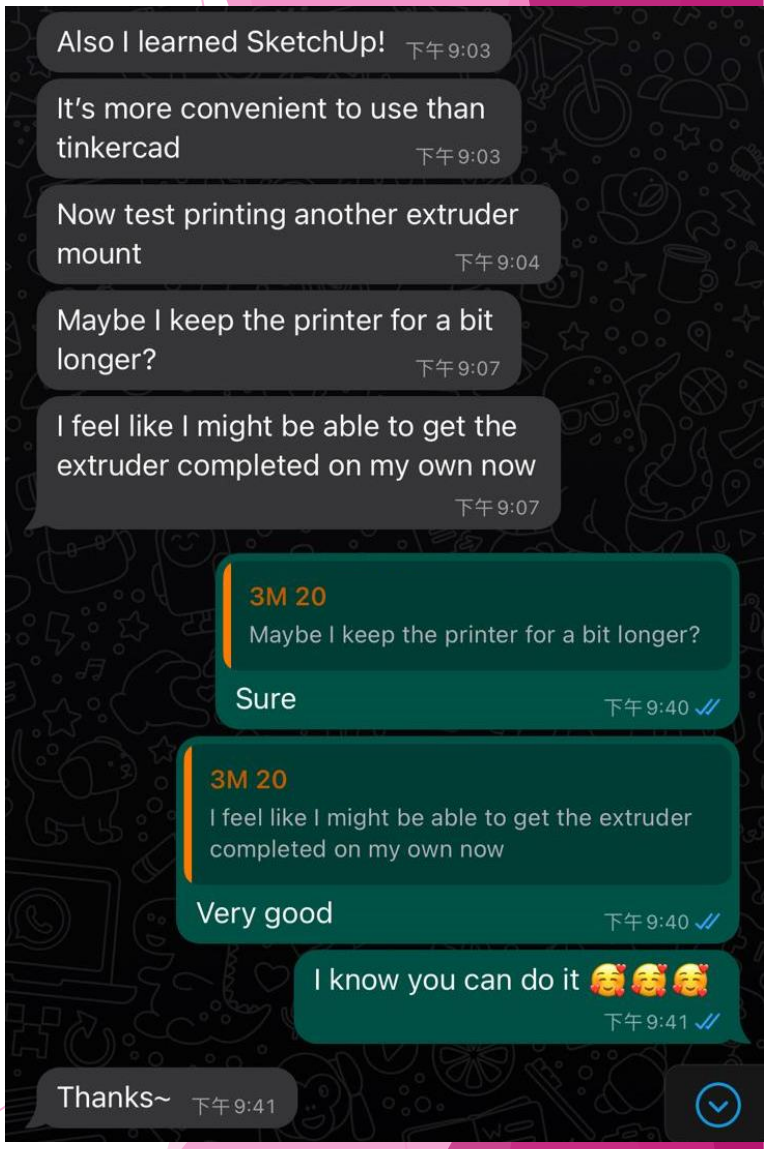


Self-learning:
Computer 3D design of parts

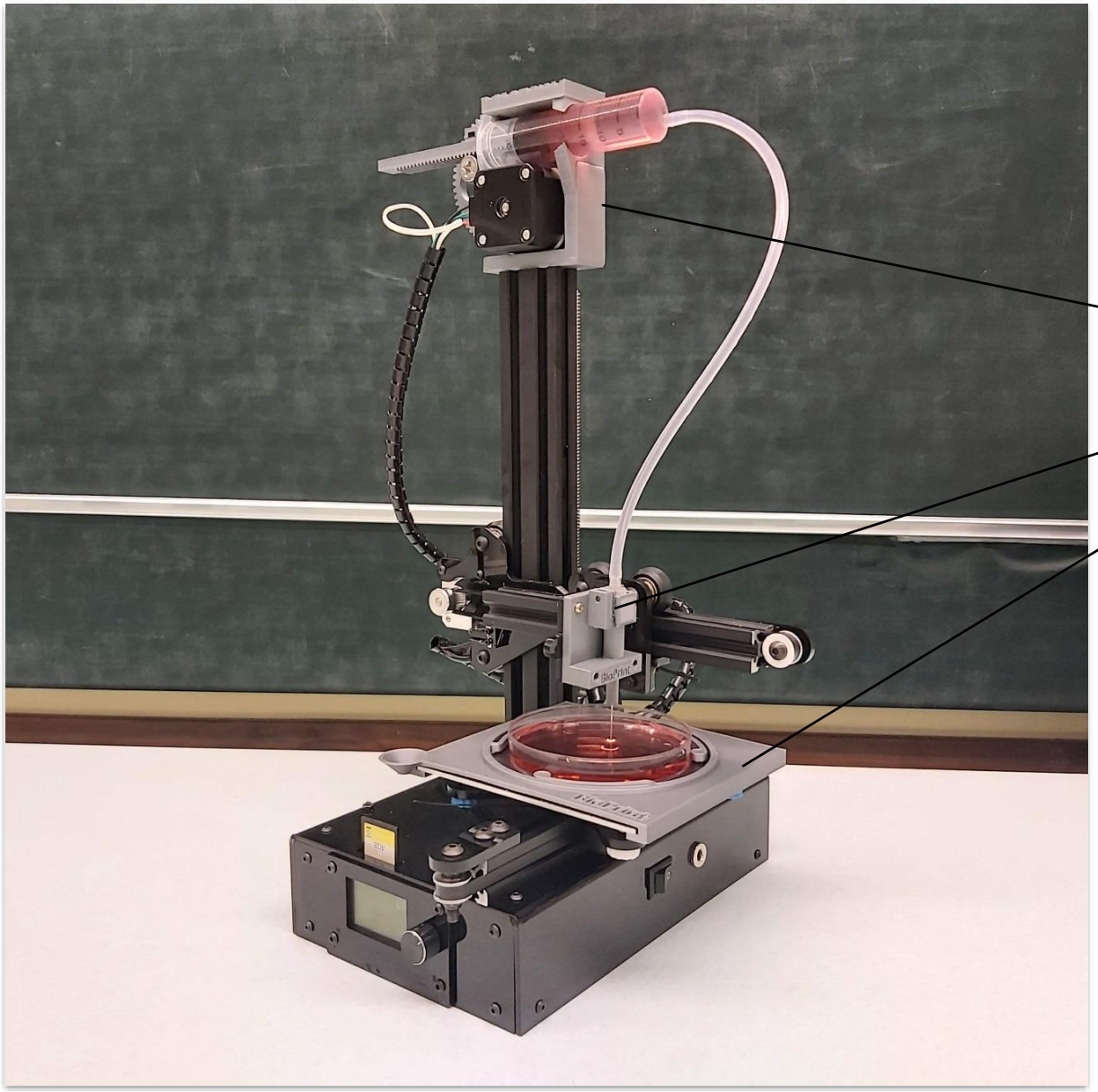
Entry-level 3D design tool



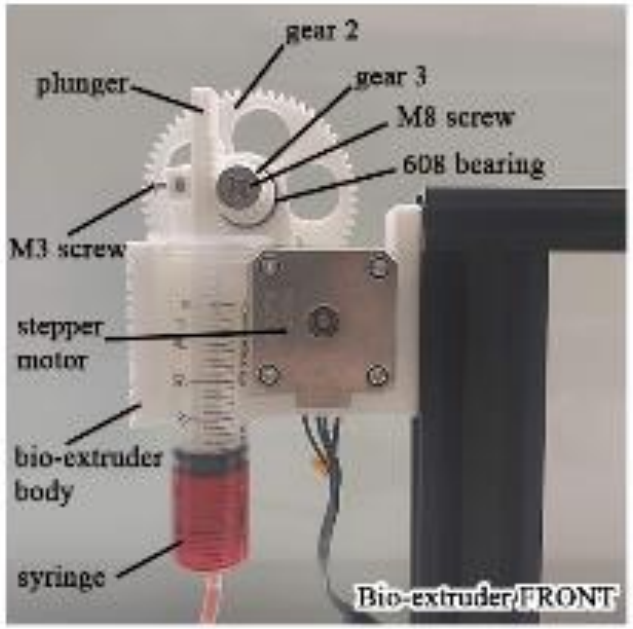
More advanced 3D modeling software

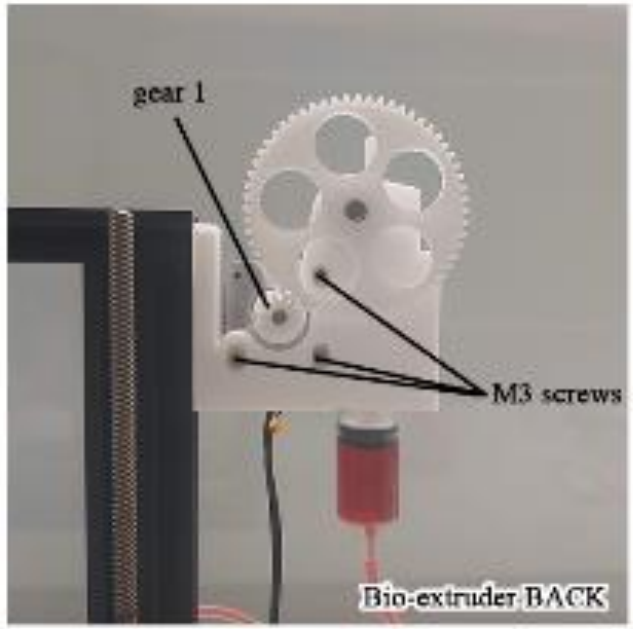


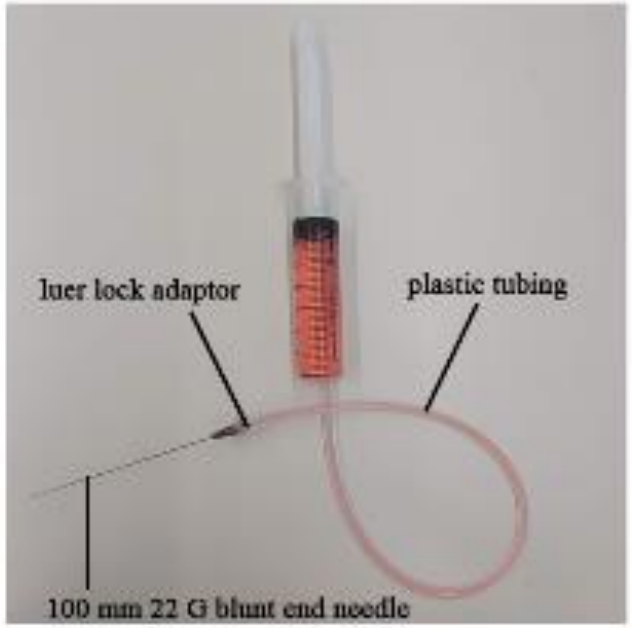
1st Prototype

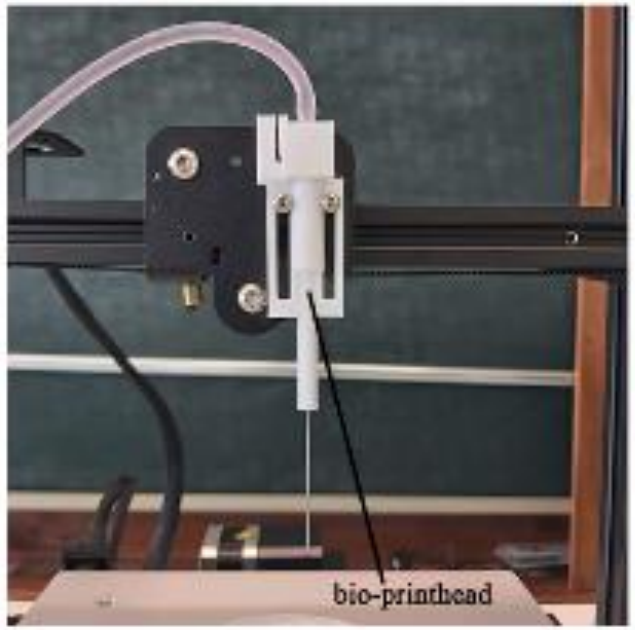


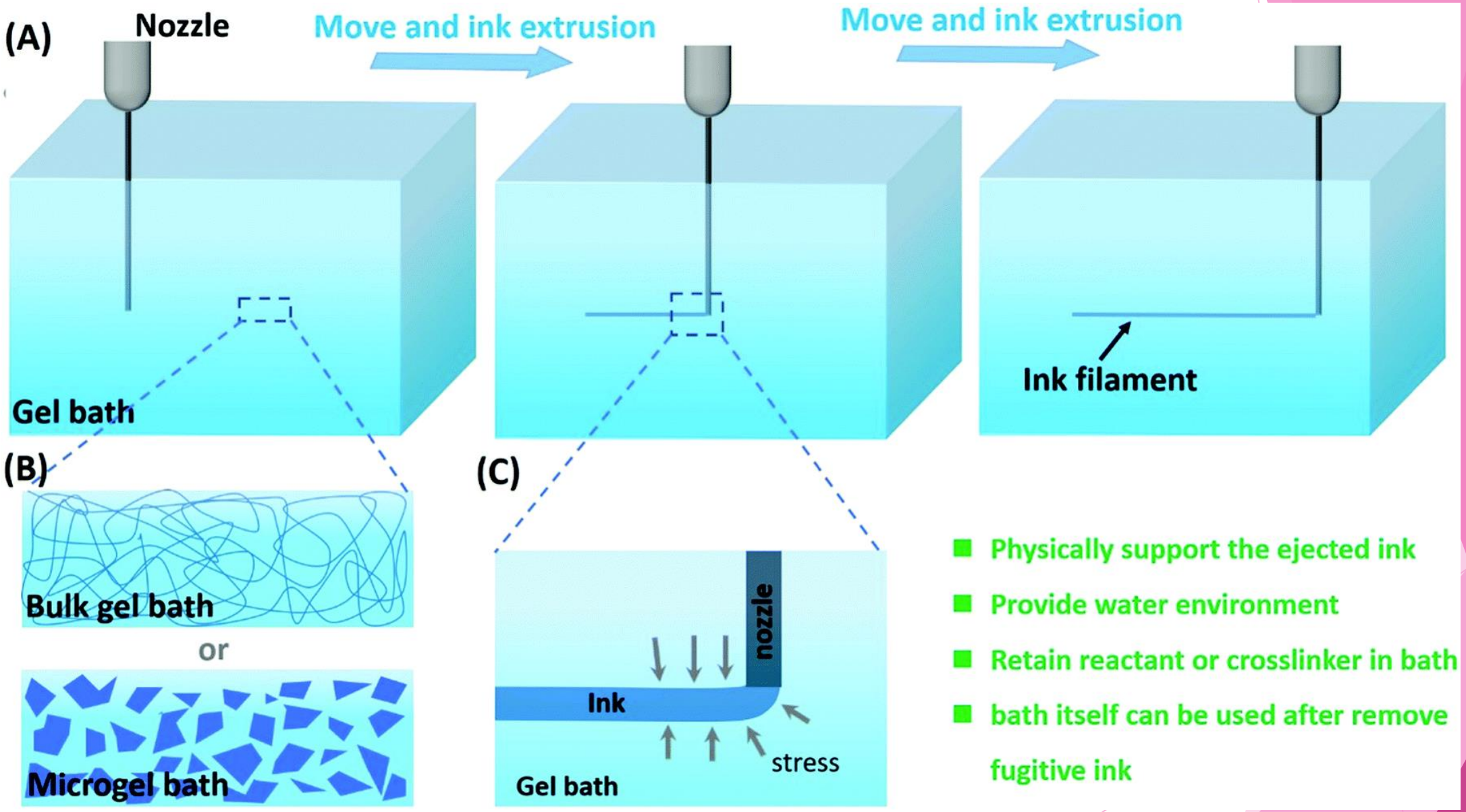
3D printed parts


gear 2
plunger
gear 3
M8 screw
608 bearing
M3 screw
stepper motor
bio-extruder body
syringe
Bio-extruder FRONT


gear 1
M3 screws
Bio-extruder BACK


luer lock adaptor
plastic tubing
100 mm 22 G blunt end needle

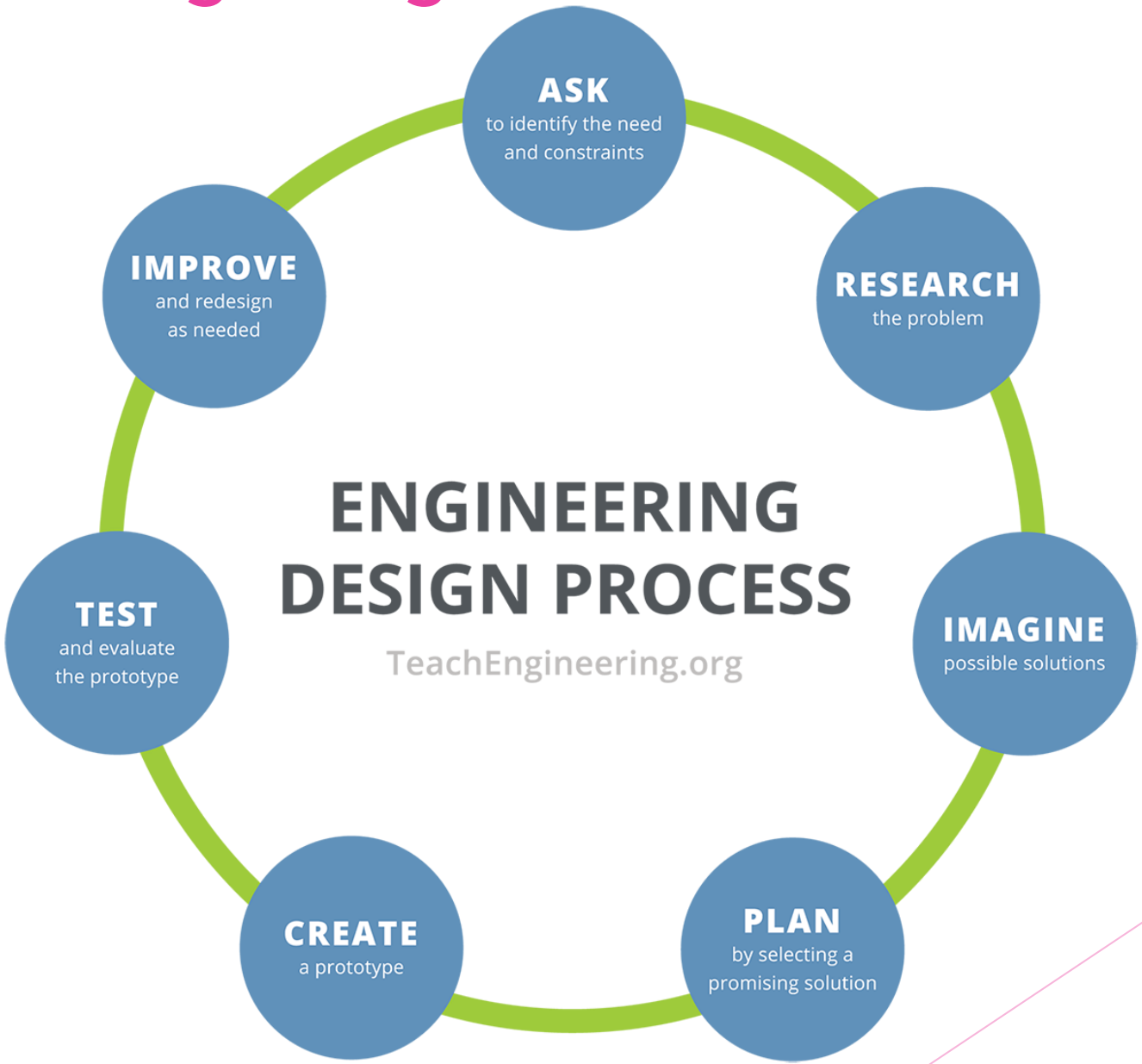

bio-printhead



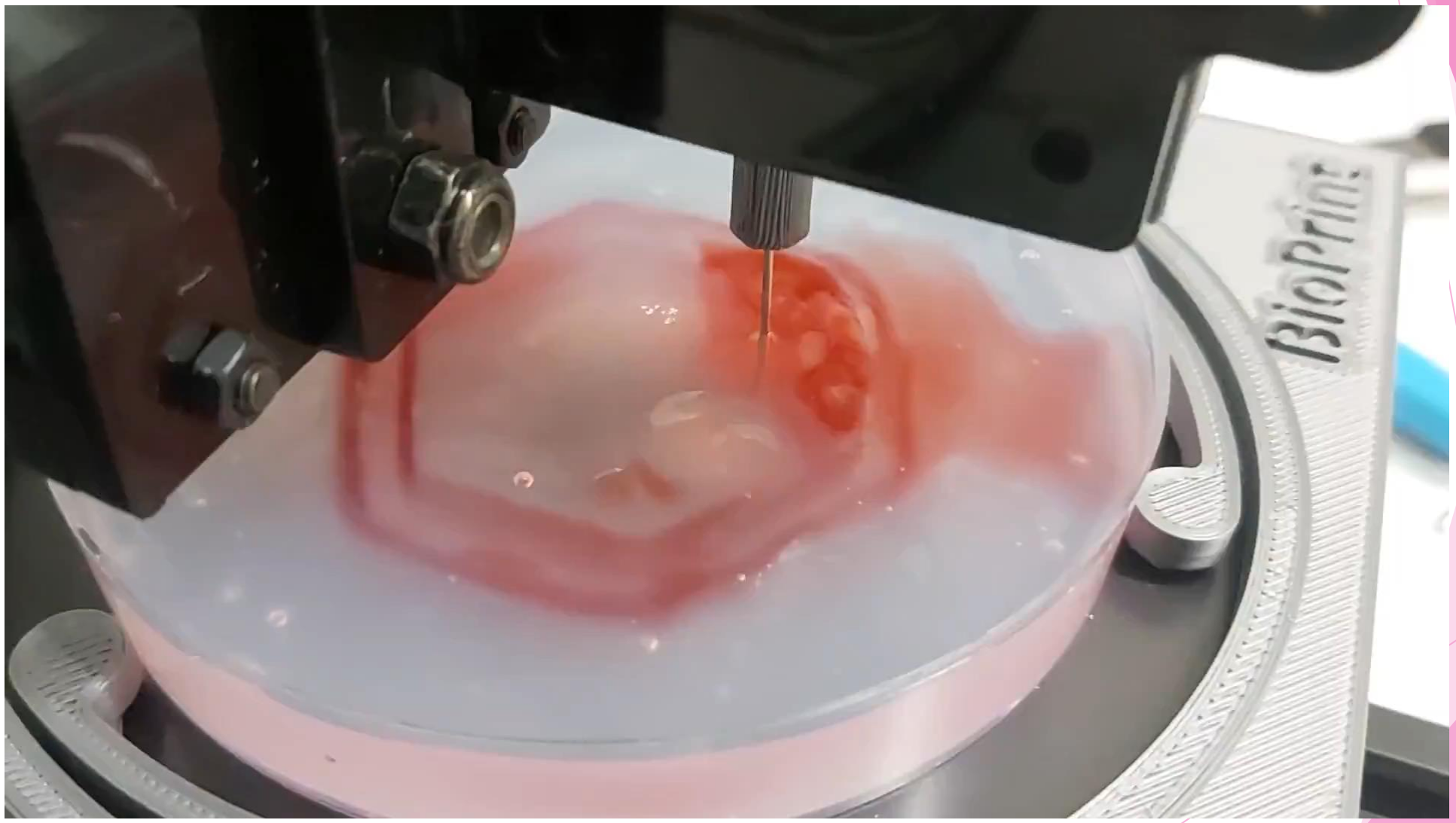
- Physically support the ejected ink
- Provide water environment
- Retain reactant or crosslinker in bath
- bath itself can be used after remove fugitive ink

First attempt

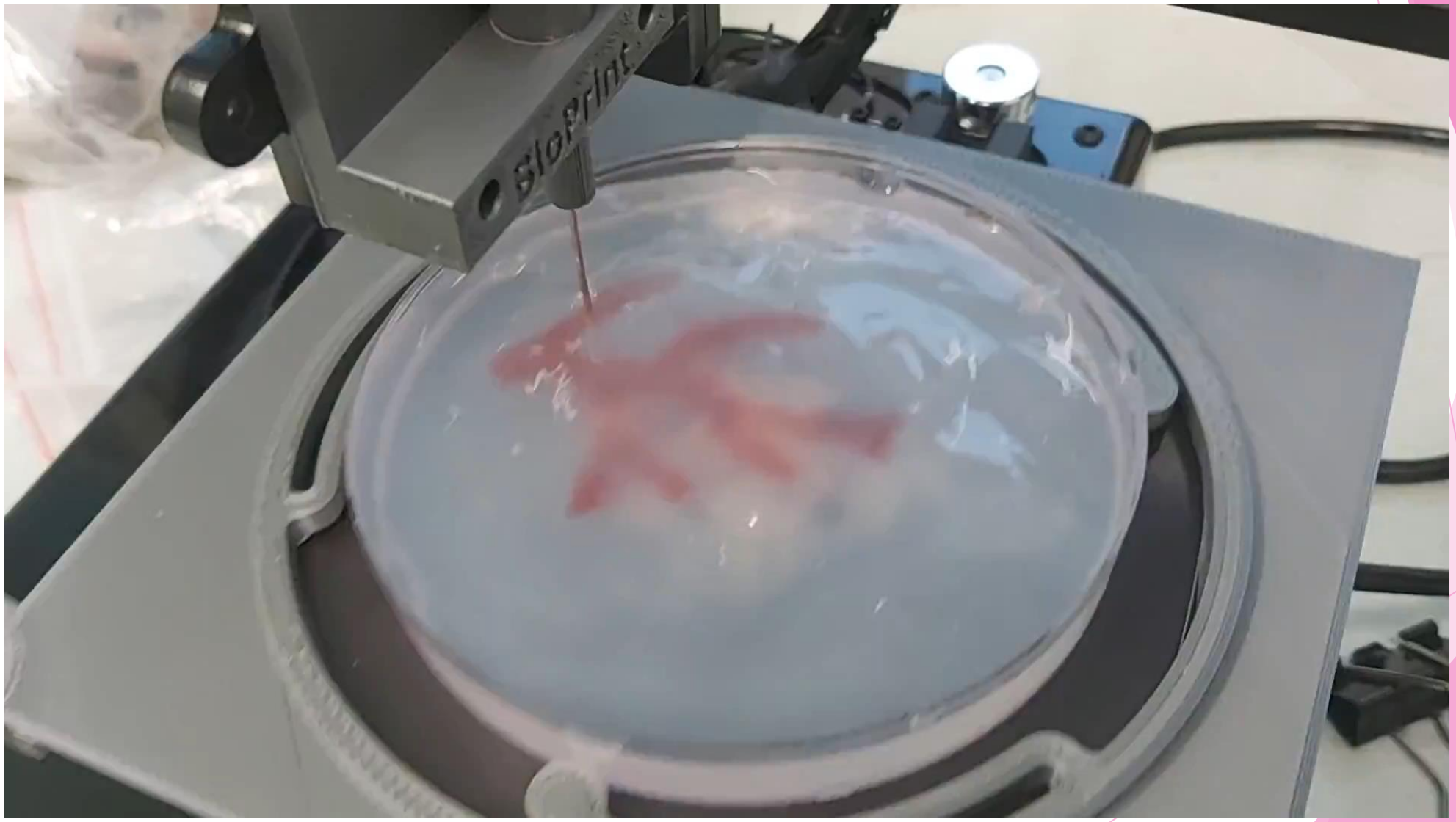
The Engineering Design Process



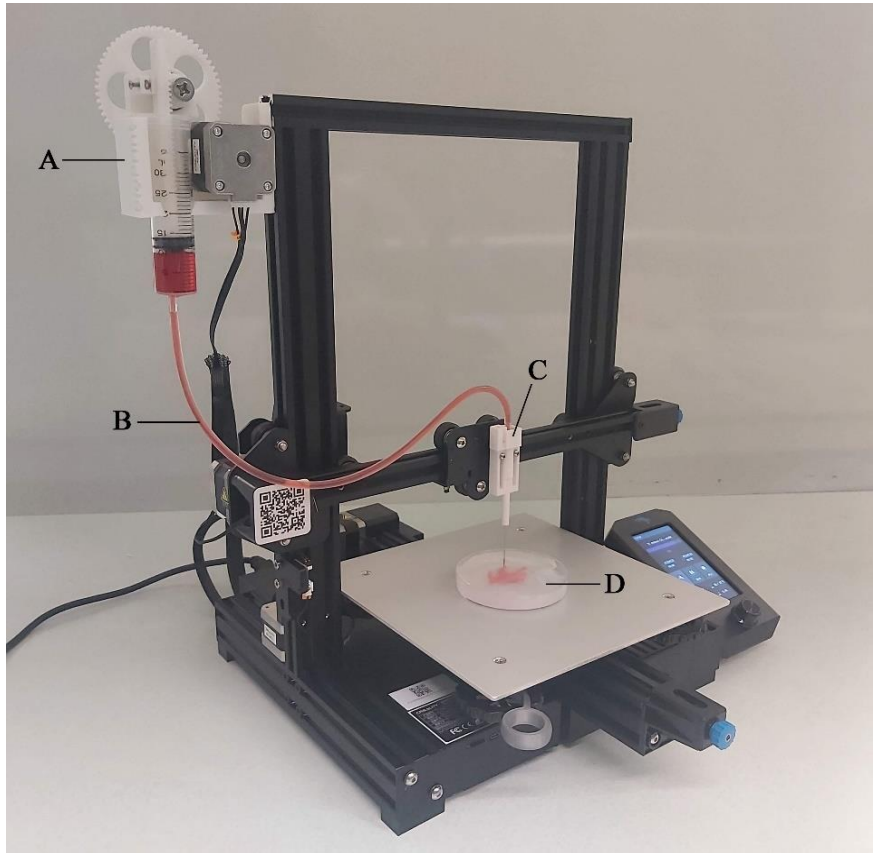
https://www.teachengineering.org/populartopics/designprocess


BioPrint

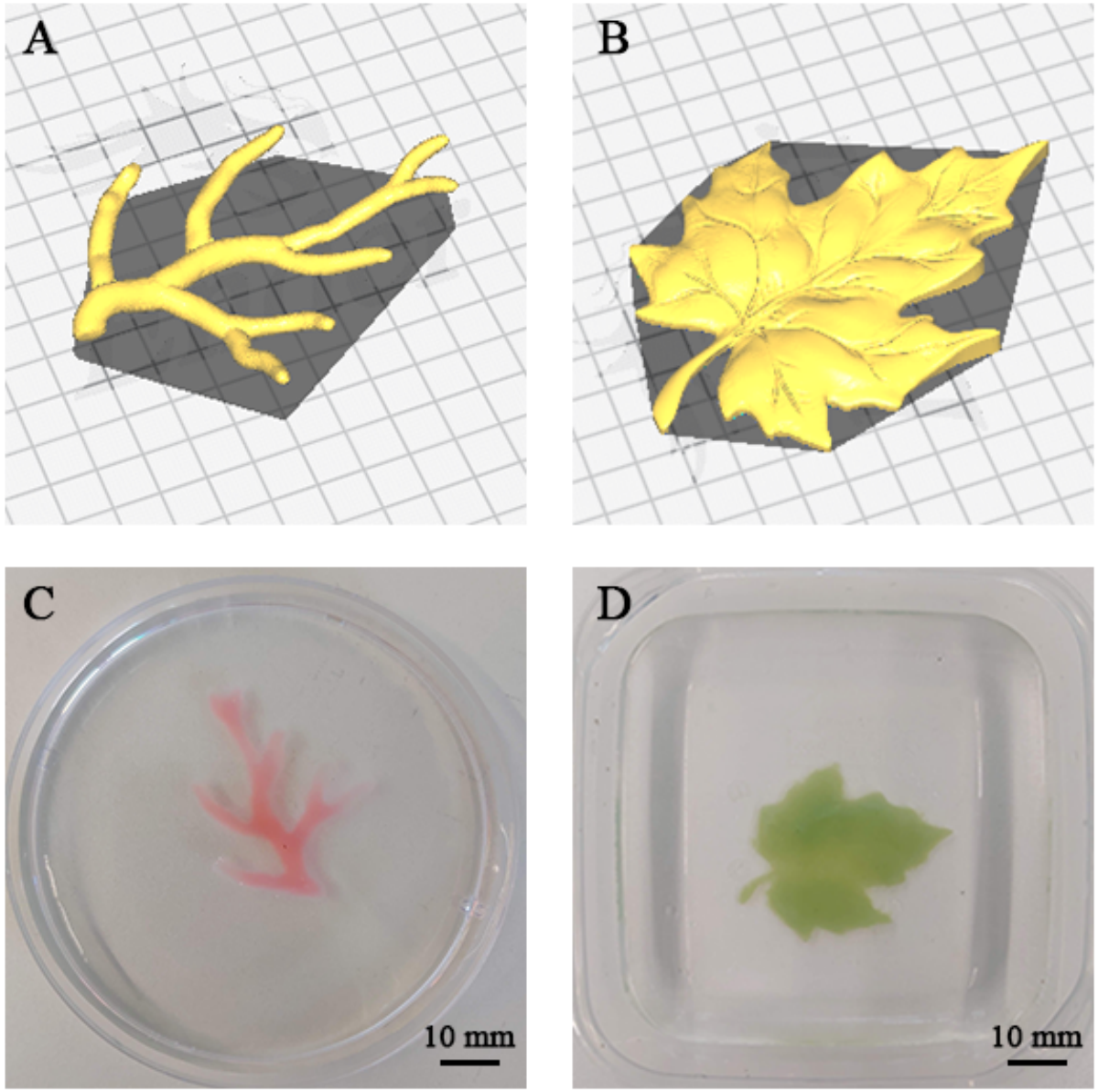
After several refinements

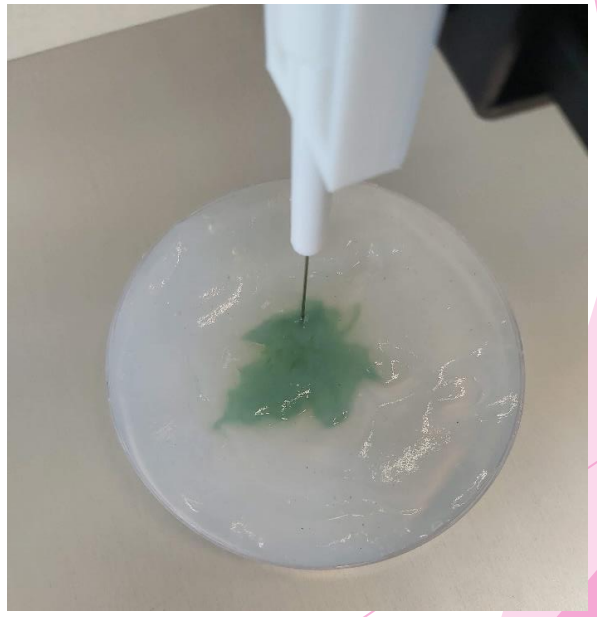


2nd Prototype



Modified Creality Ender 3 V2 3D printer





3D models (A, B) in STL format are used to bioprint a right coronary artery tree (C) and maple leaf (D) (scale bar, 10 mm).

Learning Through Publishing

J Microbiol Biol Educ. 2016 Mar 1;17(1):120-4. doi: 10.1128/jmbe.v17i1.1004. eCollection 2016 Mar.

Incorporating Primary Scientific Literature in Middle and High School Education

Sarah C Fankhauser [1], Rebeccah S Lijek [2]

Affiliations + expand

PMID: 27047607 PMCID: PMC4798793 DOI: 10.1128/jmbe.v17i1.1004

J Microbiol Biol Educ. 2022 Jan 31;23(1):e00146-21. doi: 10.1128/jmbe.00146-21. eCollection 2022 Apr.

No Science Fair? No Problem. Engaging Students in Science Communication through Peer Review and Publication in a Remote World

Eddie Rodriguez [1 2], Michael Mazzola [3 2], Sarah C Fankhauser [4 2]

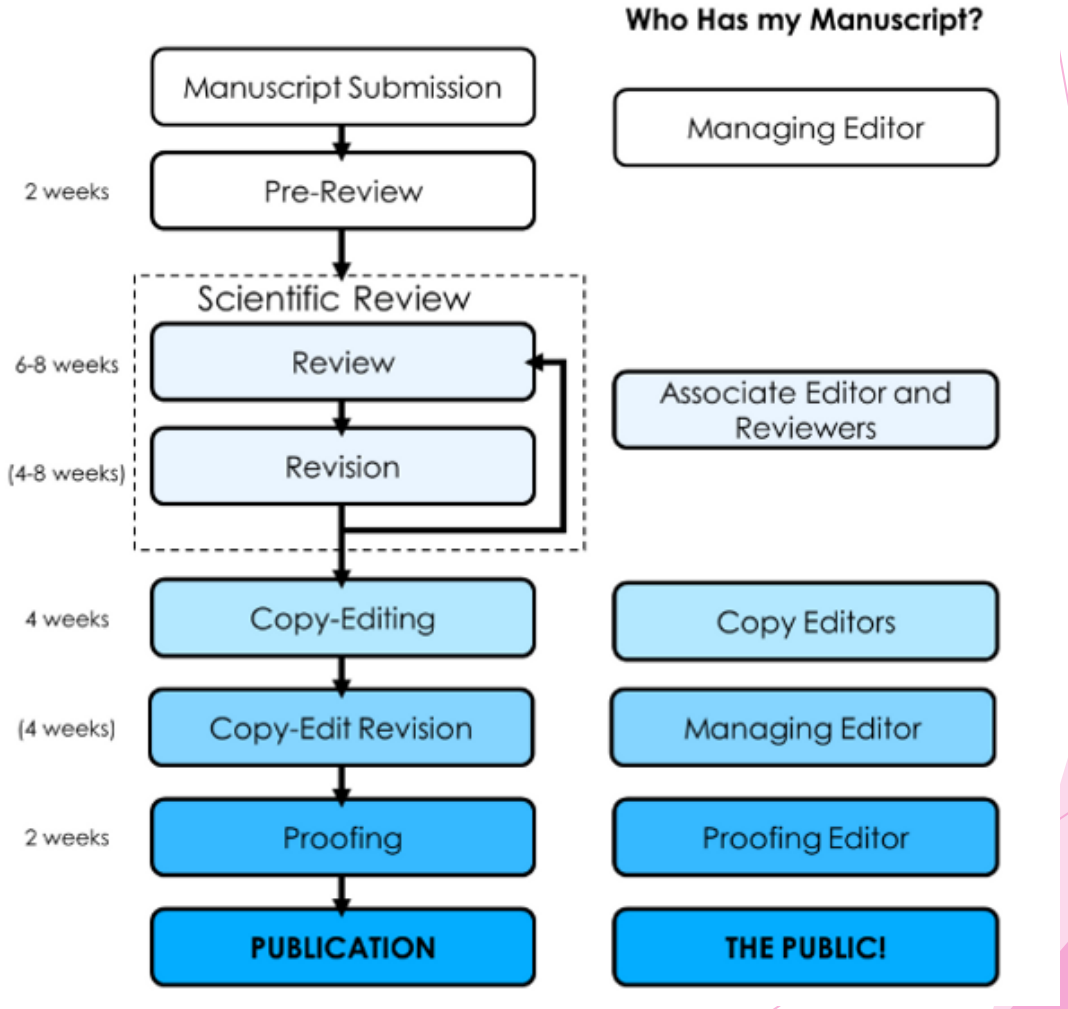
Affiliations + expand

PMID: 35340450 PMCID: PMC8943606 DOI: 10.1128/jmbe.00146-21

Nature of science

- Scientific communication
- Peer review
- Making evidence-based claims in scientific research

Journal for High School Students' Project in USA



Students' creativity can make a real impact

Suvir Mirchandani tells US government how to save £240m - just by changing their font

Suvir Mirchandani calculated that by using Garamond font instead of Times New Roman the Government could save millions

Heather Saul • Saturday 29 March 2014 16:28 GMT • Comments

Suvir Mirchandani calculated that by using Garamond font instead of Time New Roman , it would use 25 per cent less ink because each character is lighter and thinner

JOURNAL OF EMERGING INVESTIGATORS

A Simple Printing Solution to Aid Deficit Reduction

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Tips and Tools

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Inexpensive DIY Bioprinting in a Secondary School Setting

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KEYWORDS inexpensive, secondary school setting, 3D printing, bioprinting, bioprinter, bioink, alginate, algae, immobilized algae, structure-function relationship

INTRODUCTION

Recently, research in three-dimensional (3D) bioprinting has grown rapidly (1). Bioprinting allows custom printing of soft living tissue by harnessing the 3D printing technique (2). It has been shown clinically that bioprinting could help repair different types of human organs, including skin, bone, and ear (3). Bioprinting could also enhance drug discovery and allow development of new material (4, 5).

Given the great promise of bioprinting in future research and medicine, it is desirable to introduce bioprinting to secondary school students. Early exposure to bioprinting allows students to acknowledge the latest development of biotechnology, which might inspire them to become future professionals. The novelty and interdisciplinary nature of bioprinting technology makes it an attractive content for science, technology, engineering, and math (STEM) education. In addition, if bioprinting becomes available in secondary schools, cell-laden tissues could be produced on demand as teaching materials to facilitate the teaching of structure and function concepts in biology. However, unlike 3D printing of plastic, bioprinting is uncommon among secondary schools due to its high cost. A basic bioprinter might cost several thousand U.S. dollars, hindering the incorporation of bioprinting into secondary school STEM curricula (6). Researchers in the field have demonstrated ways to make do-it-yourself (DIY) bioprinters (7–9). However, those DIY bioprinters were mainly designed for research purposes, and the construction and operation of them requires uncommon reagents, professional equipment, and advanced engineering skills.

To enable exploration of bioprinting for concept clarification and experimentation in a secondary school setting, here we showcase how a Creality Ender 3 V2 3D printer can be converted into a bioprinter at low cost, using 3D-printed parts and readily available materials (Fig. 1). The DIY bioprinter prints by extruding bioink into a support medium layer-by-layer (10). The bioink contains living cells, culture medium, and sodium alginate, while the support medium contains calcium ions for solidifying the bioink and at the same time preventing the solidified bioink from collapsing during printing (10). We demonstrate how bioink and support medium could be prepared using reagents available in secondary schools. Teachers and students together used the bioprinter to print a coronary artery model and an algae-laden artificial leaf. The print quality of our bioprinter is sufficient for teachers to illustrate the rationale of bioprinting to students. Finally, the photosynthetic activity of the algae-laden artificial leaf was assessed using a hydrogen carbonate indicator, and this enabled students to observe the bioactivity of the bioprinted construct.

PROCEDURE

Modification of a commercial 3D printer into a bioprinter

The commercial 3D printer chosen to be modified in this work was a Creality Ender 3 V2 3D printer, which is currently one of the most popular low-cost 3D printers for hobbyists. As shown in Fig. 1, the 3D printer was converted into a bioprinter by using 3D-printed parts: a syringe, plastic tubes, bearing, screws, etc. The conversion was mainly done by replacing the original extruder and printhead with our bio-extruder and bio-printhead. The 3D files for our bio-extruder and bio-printhead are available online in STL format (see Appendix S1 in the supplemental material). The bio-printhead was of our own design, while the bio-extruder was designed by modifying an open-source paste extruder named Spritzstruder, designed by user kitingmare on Thingiverse (278905; licensed under the Creative Commons Attribution-Non Commercial 4.0 International open-source license). The detailed steps for assembling the bioprinter are described in Appendix S2.

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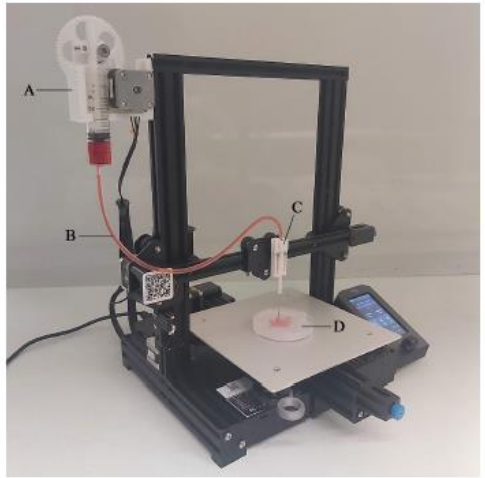

FIG 1. Components of the DIY bioprinter, converted from a Creality Ender 3 V2 3D printer. (A) A bio-extruder unit that is made up of 3D-printed parts, stepper motor, syringe, screws, and bearing. (B) A plastic tube connecting the bio-extruder and the bio-printhead. (C) The bio-printhead is made up of 3D-printed parts, 100-mm 22-gauge blunt-end needle and a luer lock adaptor. (D) Support medium on a petri dish for solidifying and supporting the bioprinted structure.

Preparation of bioink

To prepare for bioprinting, the syringe in the bio-extruder needs to be filled with bioink. To prepare 100 mL of bioink, dissolve 2 g of sodium alginate in 100 mL of cell culture to obtain bioink with 2% (wt/wt) sodium alginate. Sodium alginate can be polymerized into hydrogel when it encounters calcium ions in the support medium. In our work, we prepared an algae culture by referring to a previously described method (11). Cell culture could be replaced with colored water for testing or demonstration purposes.

Preparation of support medium

The biostructure is printed on a petri dish containing support medium. To prepare 600 mL of support medium, dissolve 4 g of agar in 400 mL of 11 mM $CaCl_2$ to give 1% (wt/wt) agar in $CaCl_2$. After solidification, add 100 mL 11 mM $CaCl_2$ solution to the agar and use a spatula to smash the agar into pieces. Then, transfer the agar solution mix to a blender and blend the mixture for 3 min to generate a Bingham plastic-like slurry. Put the slurry in a 4°C refrigerator and wait for a week to remove the air bubbles, as the presence of air bubbles could undermine print quality. If a centrifuge is available, one can quickly remove the bubbles by centrifuging the slurry at 8,000 rpm for 1 min. The prepared support medium can be stored at 4°C.

Hands-on bioprinting

To prepare 3D models for bioprinting, open-source models can be downloaded on websites like Thingiverse or NIH 3D print exchange. G-code can be generated using a slicing setting, as described in Appendix S3. The G-code could be stored in a micro-SD card and plugged into the bioprinter for printing. Before printing, the syringe in the bio-extruder is filled with bioink and a petri dish filled with support medium needs to be placed at the middle of the build plate. To ensure that the nozzle is completely filled with bioink before printing, one could press the plunger until seeing bioink coming out from the bio-printhead. After that, printing can be initiated. The printing time depends on the volume of the print. For example, printing the coronary artery, as shown in Fig. 2, requires 15 min. After printing, leave the petri dish overnight to ensure complete solidification. The 3D printed biostructure can then be isolated by washing away the support medium carefully in

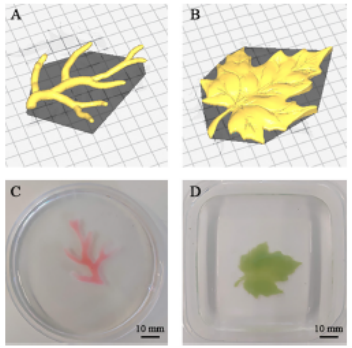

FIG 2. Two example constructs printed by the DIY bioprinter. 3D models (A and B) in STL format were used to bioprint a right coronary artery tree (C) and a maple leaf (D). Scale bar, 10 mm. The right coronary artery tree is a test print printed with 2% sodium alginate with red food coloring. The maple leaf was printed with algae culture with 2% sodium alginate.

running water. To obtain optimal print quality, see Appendix S4, which outlines questions and answers for troubleshooting.

Bioprinting an algae-laden artificial leaf and assessing its bioactivity

In this bioprinting activity, students downloaded a maple leaf model on Thingiverse (number 25938 by user MakerBot) and printed it with an algae-laden bioink, as shown in Fig. 2 (see Appendix S1 for the STL file). To assess the bioactivity of the bioprinted leaf, it is submerged in 30 mL of hydrogen carbonate indicator (see Appendix S5). Photosynthetic and respiratory activities can be demonstrated by color change of the indicator. Photosynthesis under bright light results in a net consumption of carbon dioxide and turns the indicator purple, while respiration in the absence of light releases carbon dioxide and turns the indicator yellow.

Safety issues

This work does not involve hazardous chemicals or pathogenic microorganisms. To eliminate the risk of overheating during printing, the original heater must be disconnected from the mainboard when assembling the bioprinter (see Appendix S2).

CONCLUSION

This work demonstrates how DIY bioprinting can be done in a secondary school setting by adapting an available 3D printer at low cost. We have showcased how cell-embedded biostructures can be printed with satisfactory quality and how their bioactivity can be observed by students to enhance curiosity, interest, and motivation. We believe that our work could stimulate innovative and inspirational teaching and learning attempts in secondary schools. Not only might this work stimulate the learning of bioprinting in secondary schools, but also it might stimulate creative attempts in enhancing the teaching of structure-function concepts in biology. It is recommended that educators further explore ways to integrate DIY bioprinters into structured curricula.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, DOCX file, 1 MB.

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We declare that the work was conducted in the absence of any relationships that could be construed as a potential conflict of interest.

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Summary

- Build Up a Student Talent Pool
- Pull-out Gifted Programme
- Exploring Individuals Talent
- Authentic Research
- Teacher-student Partnership
- Scientific communication