ISDN2400 Physical Prototyping

By Rob Scharff

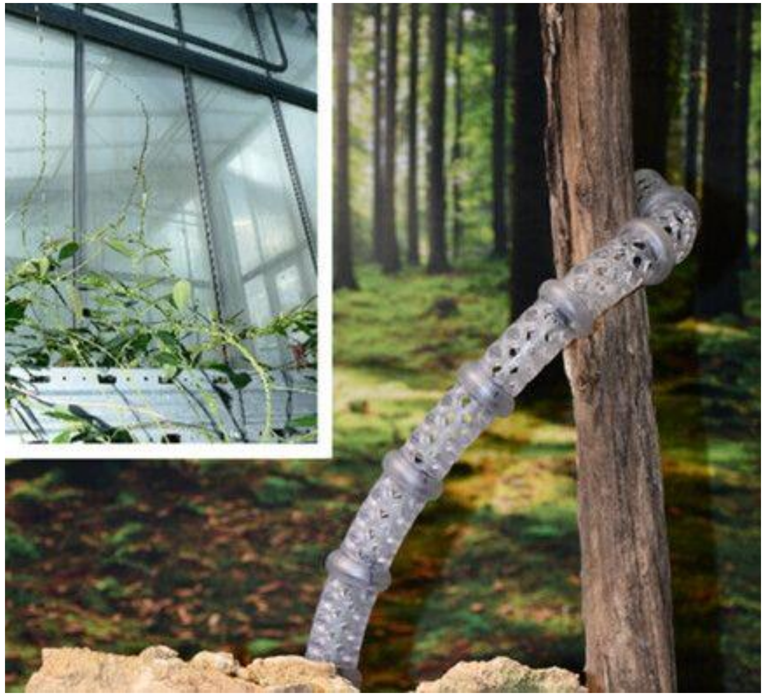
February 2025

Today's lecture

- Course introduction
- Project
- Course overview

My background

- Assistant Professor at the Division of Integrative Systems and Design and the Department of Mechanical and Aerospace Engineering
- BSc and MSc at the faculty of Industrial Design Engineering, TU Delft, The Netherlands
- Research focus: Soft Robotics
- Teaching prototyping courses since 2015



What is physical prototyping

- Prototype: *"a first, typical or preliminary model of something [...] from which other forms are developed or copied"*
- Prototypes can be digital or physical
- Prototypes allow you to test and refine your ideas
- Prototypes are a bridge between the concept and manufacturing phase

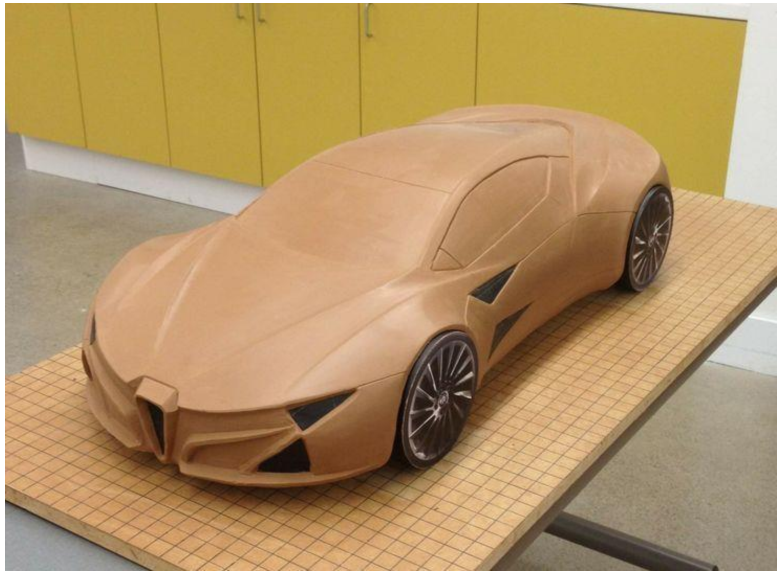
www.news.mit.edu/2020/integrating-electronics-physical-prototypes-0304

Why do we prototype?

- To understand
- To test and evaluate
- To communicate and advocate

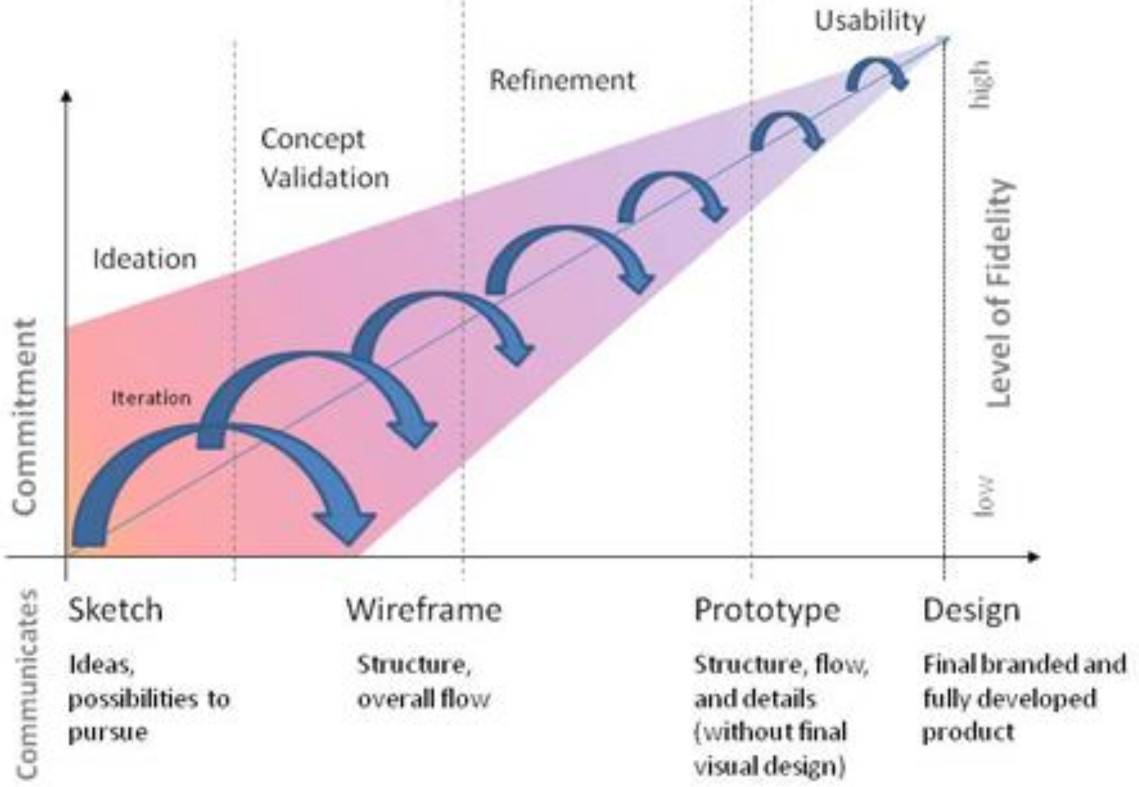
Fidelity of prototypes

- Low-fidelity / mid-fidelity / high-fidelity prototypes
- Spent resources efficiently (man hours, materials, energy, money, machine hours, etc.)
- Choice dependent on the purpose of the prototype and product development stage
- Early, low-fidelity prototypes, can save you a lot of time!

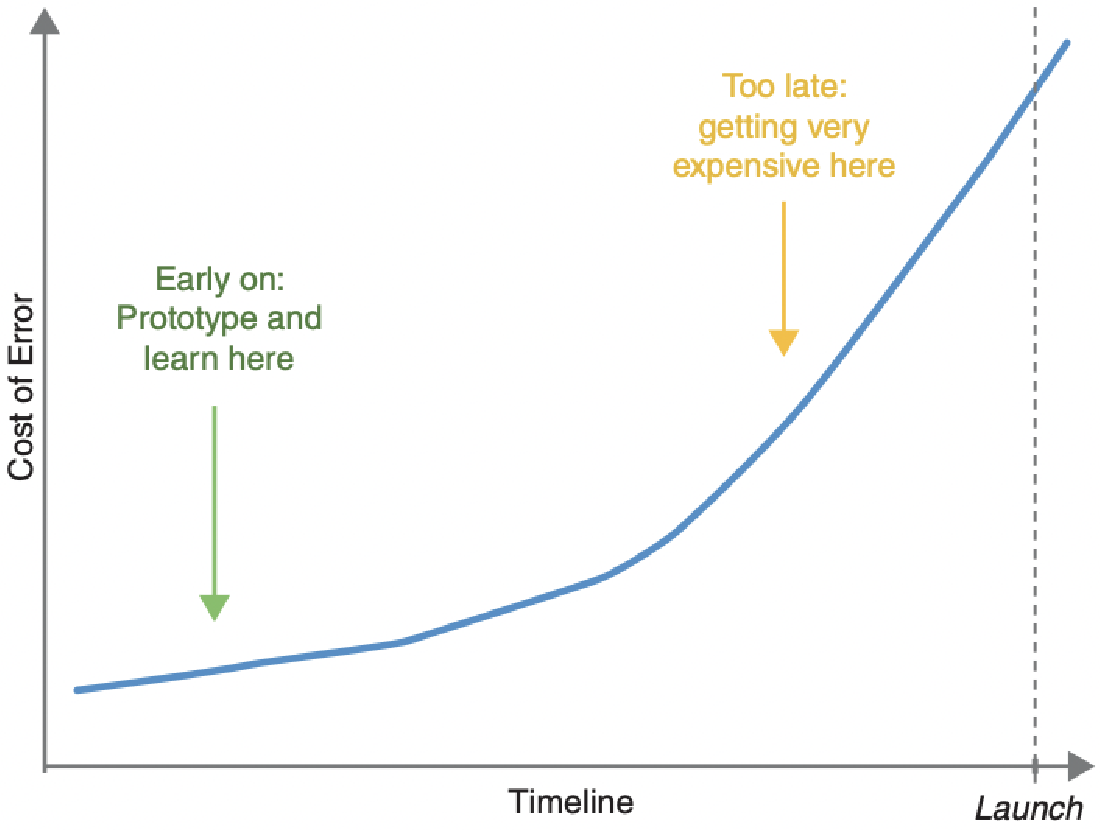


https://www.pinterest.com/pin/model-prototype-mock-up--415175659380475866/

https://www.autoexpress.co.uk/porsche/911



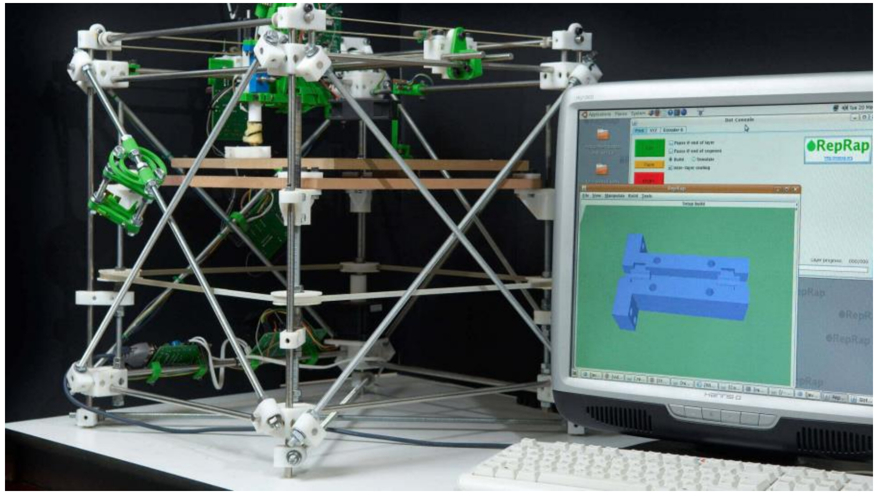
https://www.uxmatters.com/mt/archives/2010/05/sketches-and-wireframes-and-prototypes-oh-my-creating-your-own-magical-wizard-experience.php



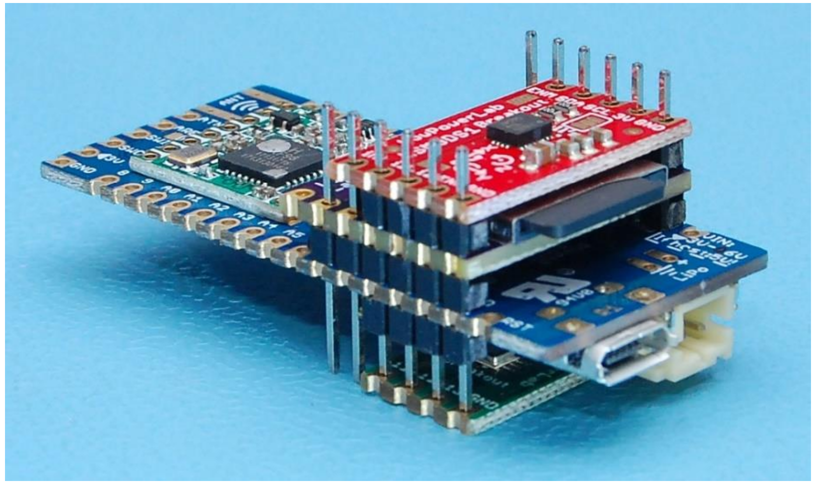
Johnsen, "Design Thinking Toolkit for Healthcare Innovation"

Enabling technologies

- Affordable and accessible digital manufacturing
  - Services like Shapeways
  - Reprap project
- Affordable and accessible microcontrollers and breakout boards



www.all3dp.com/history-of-the-reprap-project/



https://lowpowerlab.com/2018/07/07/new-products-m0-breakout-boards/

Challenges

- Design tools to fully exploit the benefits of digital manufacturing equipment

What will you learn in ISDN2400

- Use manual and computer-aided prototyping technologies to build physical prototypes
- Validate and develop proof of concept models
- Acquire skills to assemble parts into an assembled product
- Acquire skills to change concepts to desirable, feasible and viable alternatives

Prior Knowledge

- Mentimeter
- Next week’s SolidWorks lab is only compulsory to those who didn’t have SW training at ISD before
  - But feel free to join!

Structure of the Course

- Lectures focused on understanding key prototyping technologies (e.g. Additive Manufacturing, Formative Manufacturing, 3D Scanning, etc.)
- Labs focused on applying these technologies in your project

Time

- 1h20m for the labs is short!
- 33 students is a lot for some of the hands-on labs

Be on time!

- Lectures: Tuesday 16:30-17:50
- Labs: Tuesday 12:00-13:20
- 15% of the final grade is course attendance
- We need every minute of lab-time!

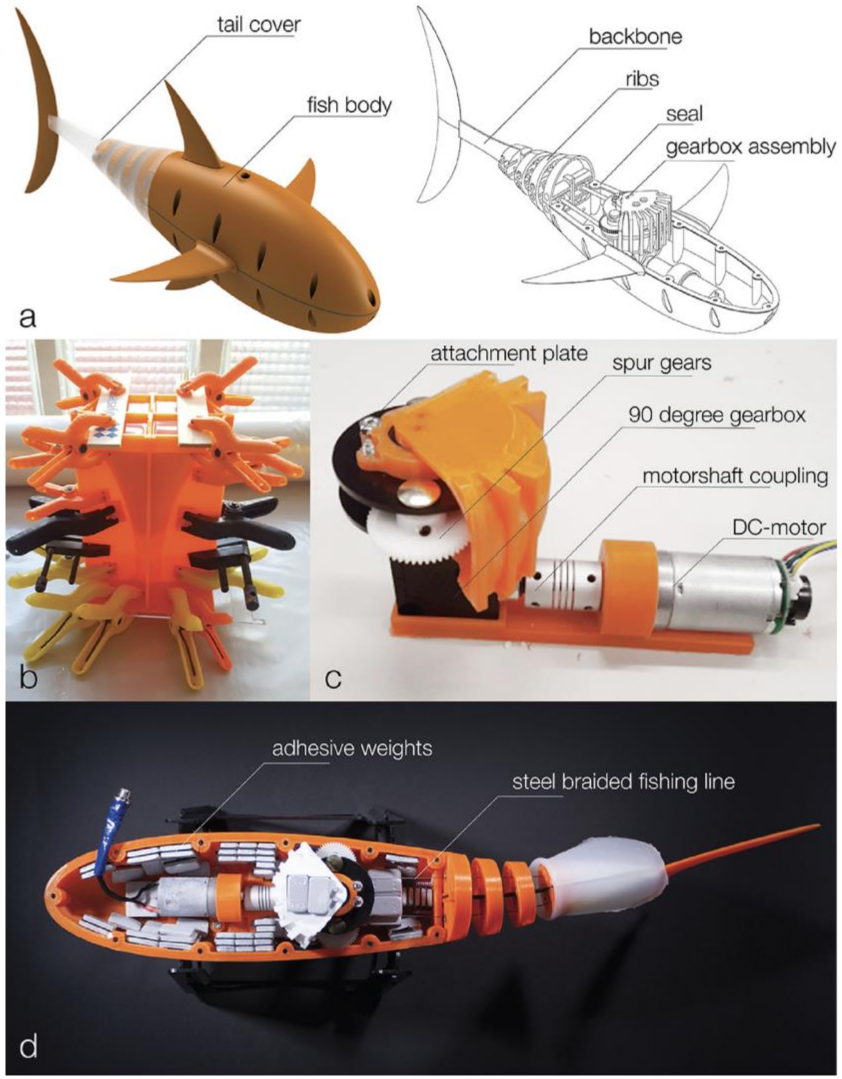
This year's project…

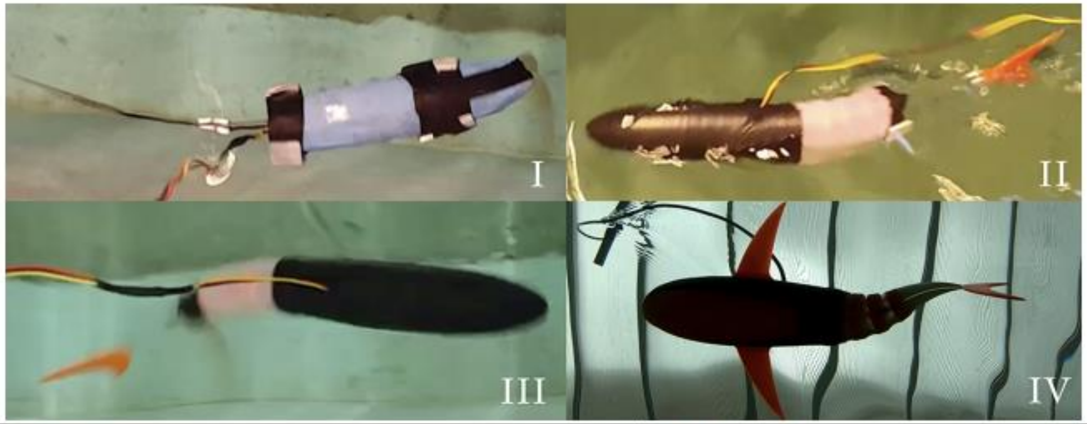
- Build a fast swimming robotic fish based on the *OpenFish* design
- Deploy the skills acquired in the labs:
  - CAD modelling
  - Fused Deposition Modelling
  - Lasercutting
  - CNC milling
  - Silicone casting
  - Electronics
  - Assembling
- Teams of 3 or 4
- Demonstrate the fish performance in a swimming competition


Flapping has major benefits as compared to
conventional propellers

You don't have to start from scratch…

- Design and fabrication files accessible online: https://osf.io/gsnc2/files/osfstorage
- Detailed build instructions documented: https://www.sciencedirect.com/science/article/pii/S2468067222000657
- Critical components have already been ordered
- Many prototyping iterations preceded the *OpenFish* design





Prototype	Description	Performance
I	Driven by servomotor	∼ 0 bodylengths per second (BL/s)- Significant head sway, minimal bending of the passive compliant tail
II	Extension piece between the head and the tail to move the center of buoyancy and center of mass from the active tail into the passive head, and increase the surface area on the anterior portion of the fish.	∼ 1.0 BL/s Improved forward motion and stability. Still significant head sway and roll instability.
III	Redistribution of mass and volume to the anterior part of the robotic fish. Increased caudal fin height and reduced chord width	1.2 BL/s - Sufficiently stable in all directions for continuous forward swimming. Minor head sway and minimal roll is observed.
IV	Servomotor replaced by a DC motor with gearbox. Width and length of the body increased – thunniform head shape.	2.0 BL/s - Stable and high speed swimming. Bending of the passive compliant tail creates a S-shaped tail for more efficient swimming

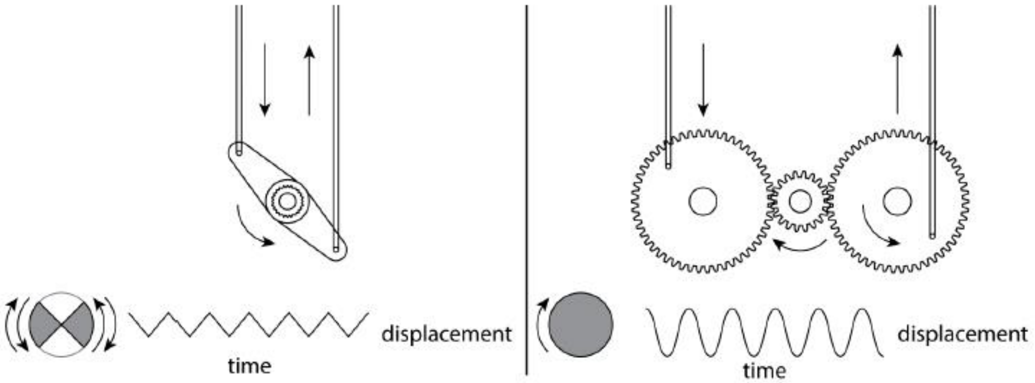


Figure 6.2: On the left a servo driven design, on the right the basic principle of the DC motor driven design. A graph of vertical displacement of the wires over time is depicted underneath both illustrations.

			
	Changes Anchoring does not put pressure on the gears or shaft anymore.	**Changes** Size of the system is increased to enable better anchoring. Ball Bearings are introduced to turn more smoothly.	**Changes** A right angle gearbox is used to reduce the height of the system allowing very large motors to be implemented if needed. An extra overhang is used with ribs to increase stiffness and decrease movement of the gearbox at high rotations.
Results Barely ran, too much play when bolts are not tightened enough. Does not turn when bolts are tightened.	**Results** Significant undesired movement within the gearbox. Needs more anchoring.	**Results** Steering system works successfully. No undesired vibrations. Stable and fluent motion of the gearbox. The four anchoring point on the outside of the gearbox make it too large.	**Results** Gearbox runs very smooth.

But there is a lot to improve!

Design issues:

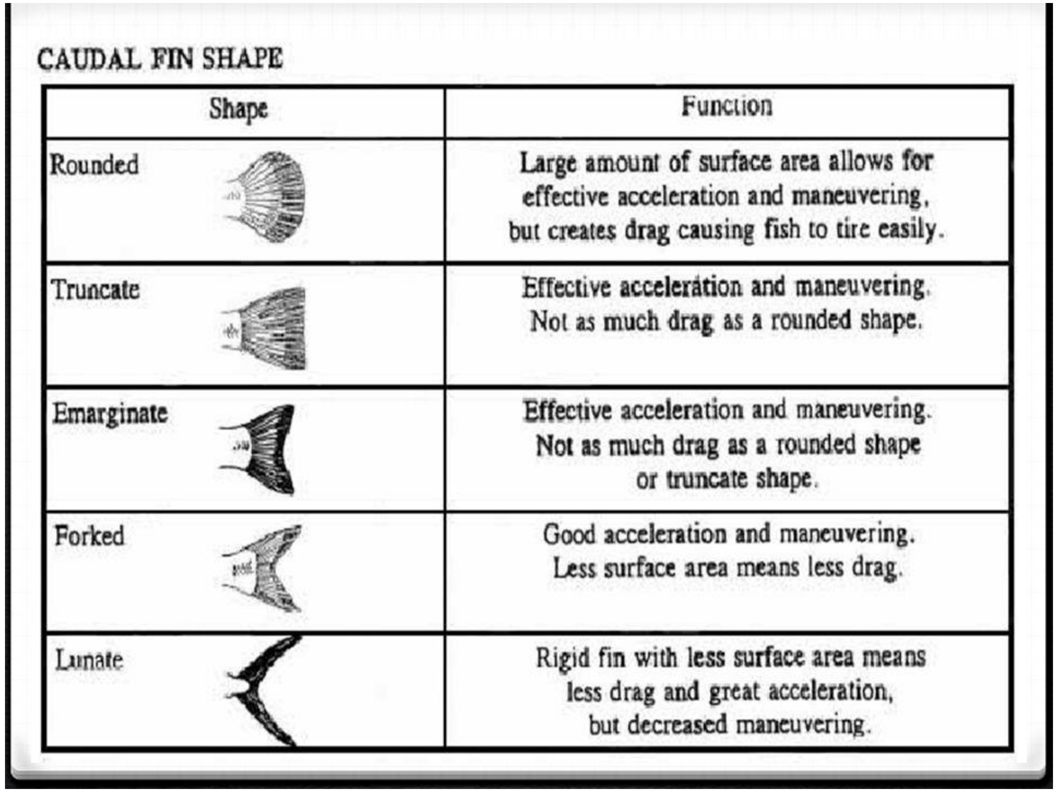
- Applying cable tension
- Sealings
- Pressure on the soft tail at greater depths
- Distribution of weights for neutral buoyancy
- Some off-the-shelf components have different dimensions → design modifications needed to fit them in

Performance improvements:

- Shape of the caudal fin
- Shape of the body

New features:

- Steering
- Battery
- Communication
- Depth control
- Embedded cameras



CAUDAL FIN SHAPE

Shape	Function
Rounded	Large amount of surface area allows for effective acceleration and maneuvering, but creates drag causing fish to tire easily.
Truncate	Effective acceleration and maneuvering. Not as much drag as a rounded shape.
Emarginate	Effective acceleration and maneuvering. Not as much drag as a rounded shape or truncate shape.
Forked	Good acceleration and maneuvering. Less surface area means less drag.
Lunate	Rigid fin with less surface area means less drag and great acceleration, but decreased maneuvering.

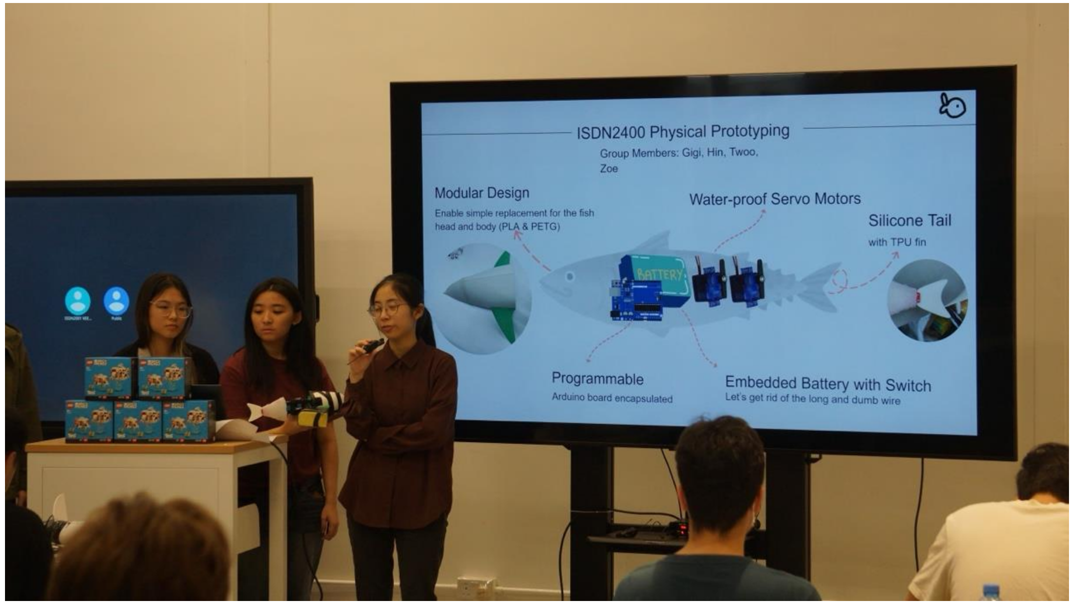
https://slideplayer.com/slide/9112605/

Why this challenge?

- Underwater environment is very unforgiving
  - Leakage? → fish will break
  - Bad weight distribution? → fish will not be stable
- Poor assembly of the mechanism? → fish will not swim straight/ efficiently
- All components are dependent on each other → Holistic approach required
- Good prototyping strategy critical
- Attention to detail and prototyping of the highest quality critical!

Competition Day

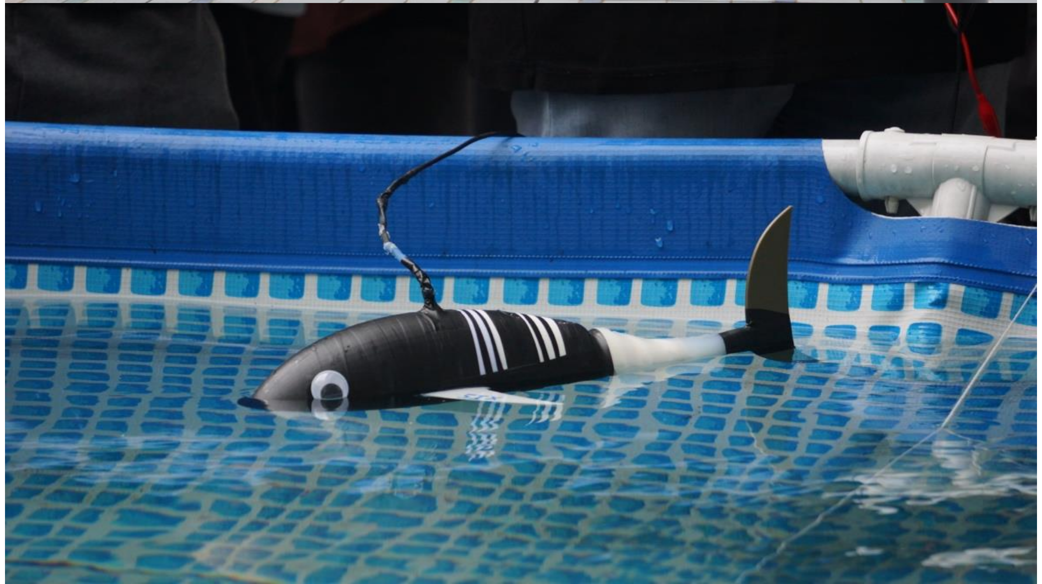
- Present your prototype's unique features
  - 1-minute pitch
  - 1 slide



Competition Day

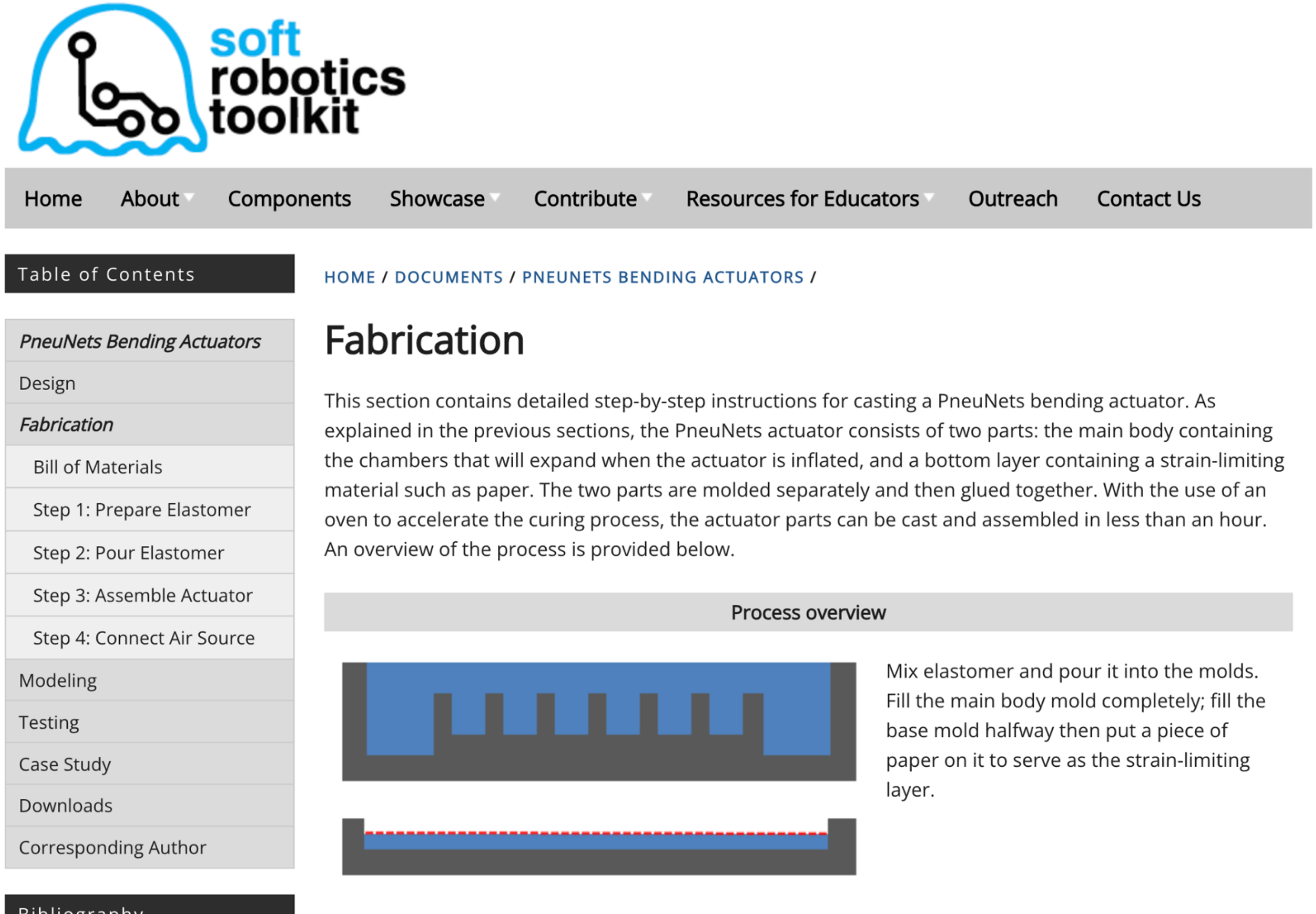
- Testing in swimming pool outside
- Swim from one side to the other side as fast as possible
  - Fastest fish in terms of bodylengths per second (BL/s) wins!
- Trophy for the team with the fastest robotic fish

Competition Day



Report

- Step by step instructions with videos and images.
- Example: https://softroboticstoolkit.com/book/fr-fabrication
- Best report will be submitted to contribute to the soft robotics toolkit: https://softroboticstoolkit.com/contribute



Inspiration

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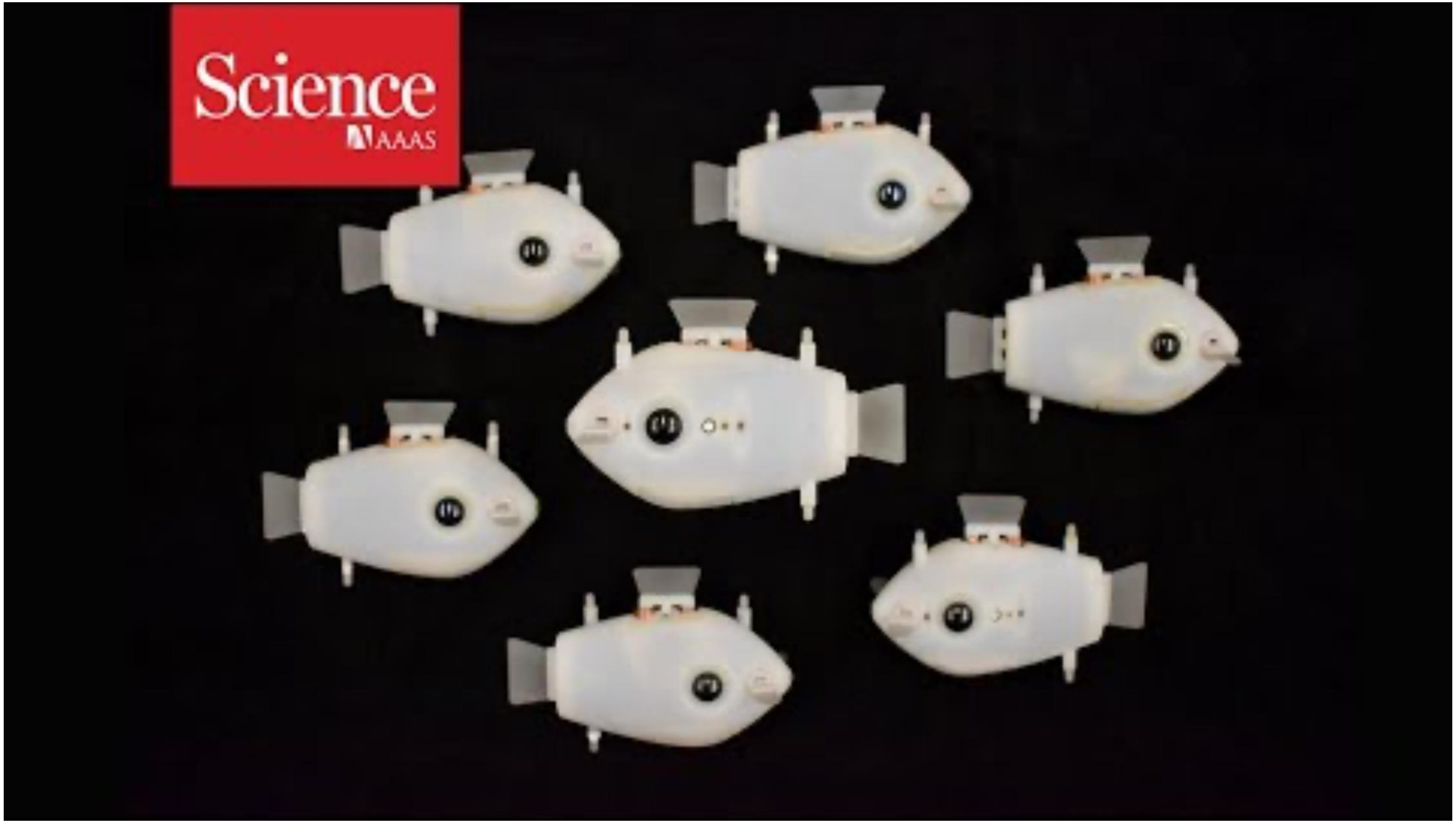

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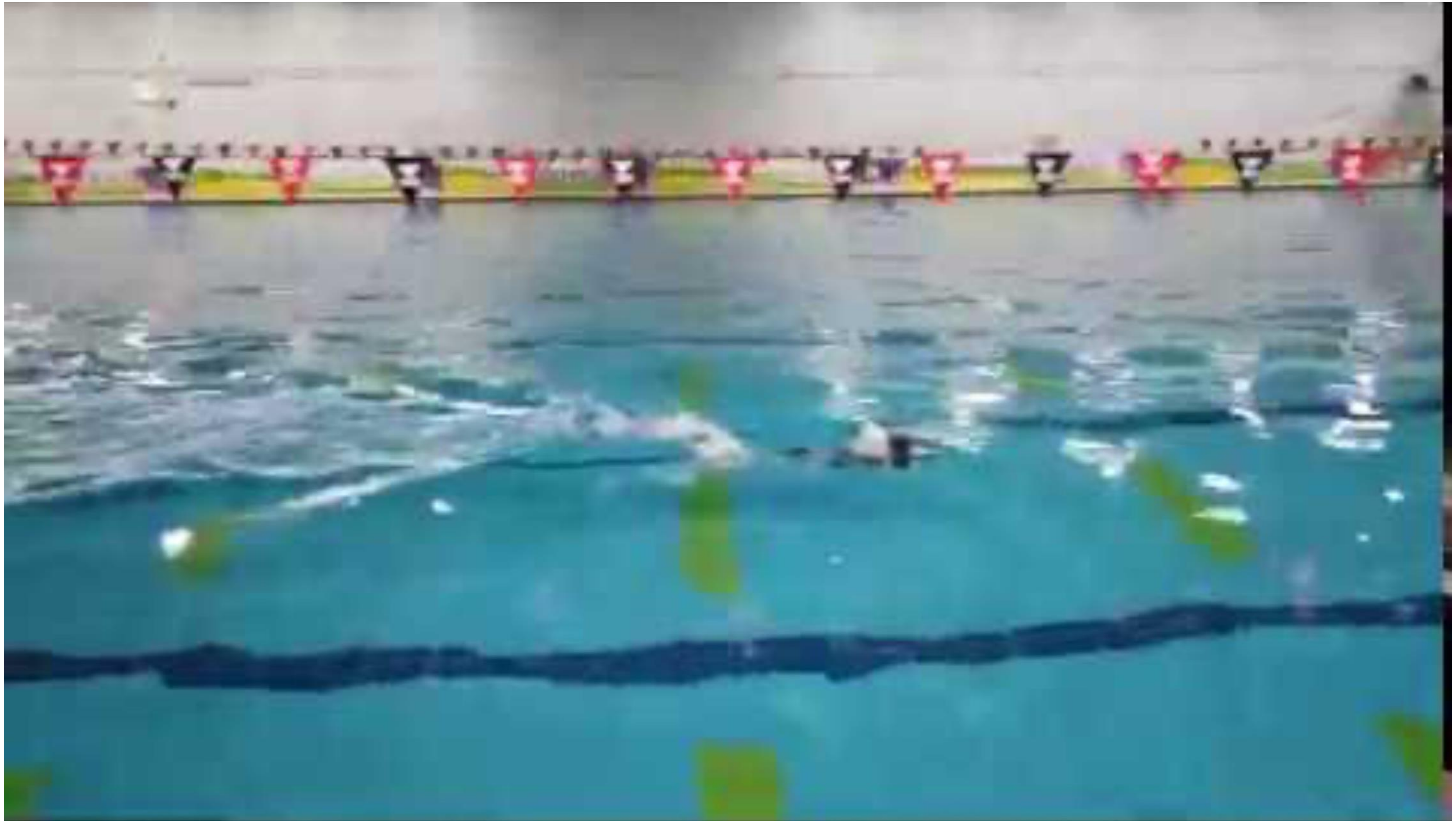

Inspiration

Assignment II: 3D Scanning & Multi-Material Additive Manufacturing

- Stratasys J850
  - Full-color
  - Transparent materials
  - Rigid and soft materials

Stratasys

Assignment II: 3D Scanning & Multi-Material Additive Manufacturing

- Everyone will 3D scan an object and 3D print it

Schedule

Week	Date	Activity
1	Tue, Feb 4	Lab: -
	Tue, Feb 4	Lecture: Introduction to ISDN2400
2	Tue, Feb 11	Lab: SolidWorks I *(SolidWorks II – TBA)*
	Tue, Feb 11	Lecture: Additive manufacturing I
3	Tue, Feb 18	Lab: Fused Deposition Modelling
	Tue, Feb 18	Lecture: Subtractive Manufacturing
4	Tue, Feb 25	Lab: Laser Cutting
	Tue, Feb 25	Lecture: Formative Manufacturing
5	Tue, Mar 4	Lab: Silicone Casting
	Tue, Mar 4	Lecture: Electronic Prototyping
6	Tue, Mar 11	Lab: DC motor control
	Tue, Mar 11	Lecture: Mechanisms
7	Tue, Mar 18	Lab: Assembling the Robot Fish
	Tue, Mar 18	Lecture: Additive Manufacturing II
8	Tue, Mar 25	Lab: Stereolithography and Digital Light Processing
	Tue, Mar 25	Lecture: Optimizing your design through iterative prototyping - Inspiration

Schedule

Week	Date	Activity
9	Tue, Apr 1	Lab: - *(Mid-Term Break)*
	Tue, Apr 1	Lecture: - *(Mid-Term Break)*
10	Tue, Apr 8	Lab: PolyJet Multi-Material Additive Manufacturing
	Tue, Apr 8	Lecture: 3D Scanning
11	Tue, Apr 15	Lab: 3D Scanning
	Tue, Apr 15	Lecture: -
12	Tue, Apr 22	Lab: Testing Robot Fish
	Tue, Apr 22	Lecture: Quiz (15%)
13	Tue, Apr 29	Lab: Testing Robot Fish
	Tue, Apr 29	Lecture: -
14	Tue, May 6	Lab: Competition Day
	Tue, May 6	Lecture: -

Grading

- Course participation 15% (individual)
- Labs/Assignments 25% (individual)
- Quiz 15% (individual)
- Project 45% (group)

The team

- Rob Scharff (scharffrbn@ust.hk)
- TA: Terence Cheung (ieterence@ust.hk)
    - CAD modelling

- PG TA: Simon Luo (yluobl@connect.ust.hk)
    - Subtractive manufacturing
    - Additive Manufacturing
    - Casting
    - General questions (e.g. absence)

- PG TA: Eric Liang (yuchen.liang@connect.ust.hk)
    - Assembly of the robotic fish
    - Testing of the robotic fish
    - Components and their functions

Questions?

Form your team

- Maximum of four students per team
- At least one ISD student to ensure access to 4223
- Preferably:
  - At least one student with some SolidWorks experience
  - At least one student with some 3D-printing experience
  - At least one student with some electronics experience