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What Flies Like a Dragonfly and Swims Like an Eel? Bio-inspired Design Cornerstone Projects

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1.0 Introduction

Biologically inspired design is a challenging topic to teach, especially to beginning first year engineering students with no background in engineering skills and analysis. At the Schulich School of Engineering, University of Calgary we have incorporated bio-inspired design as a project and successfully run a design challenge with first year engineering students, to present an additional component to the traditional design process[1] of specifying the:

- Design Problem
    - Problem Statement
    - Functional Requirements
    - Constraints
- Design Options
- Selection
- Prototyping
- Testing and Validation

Students were given a biomimicry presentation by a company that researches bio-inspired design solutions and given the opportunity to study technical details of biomimetic aircraft (dragonfly and albatross), to see how technology could be mapped to create biomimetic motion. Students were given small, elastic-band powered "flyers," which they built and tested, to understand how simple mechanisms could be used to create biomimetic motion. Students were then instructed to study biological means of movement through water, and to create a watercraft that could travel through water. This successful project resulted in many different designs, illustrating a variety of biological solutions. This paper will discuss a bio-inspired design methodology illustrated with student designs and will discuss lessons learned.

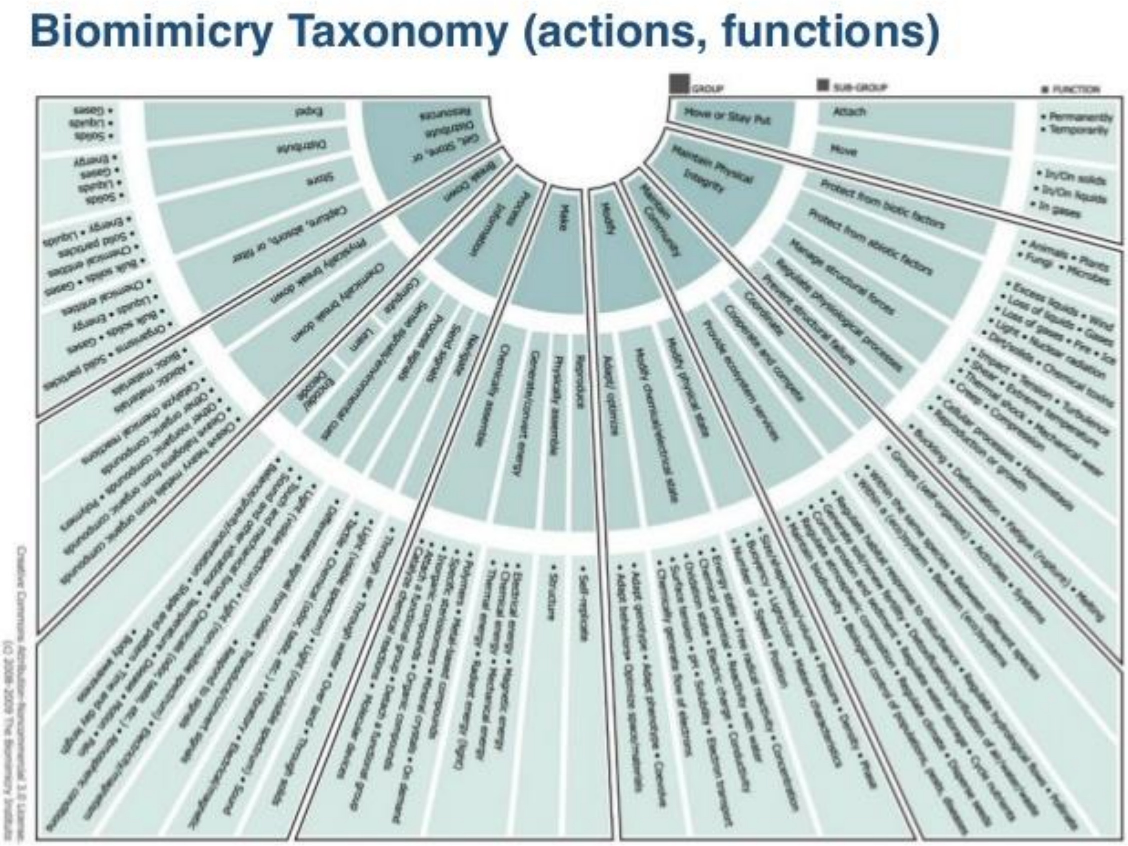

Figure 1 Biomimicry Taxonomy, Biomimicry Institute CC BY-NC 3.0

2.0 The Project

Biomimicry can be a useful design approach for engineers, following nature's evolution to adapt life to its environment. It can be a challenge for engineering students (and other non-biologists) to look at all of nature for design inspiration. One tool that has been particularly useful for our projects has been the Biomimicry Taxonomy (Fig. 1) which is the classification system used by the website AskNature.org which categorizes the ways in which organisms and natural systems address everyday challenges.[2] Biology is grouped by function making it easier for students to search for solutions once they understand what the design has to do when defining functional requirements in the Design Problem stage. In this case the function for the project was found in the group 'Move or Stay Put', in the subgroup 'Move', with the corresponding function 'In/On Liquids' (Fig. 2). Searching the website in this way, students then found 77 strategies used by organisms and natural systems, which informed their design (Fig. 3) when exploring Design Options. As students move through the remaining design process steps of selecting, prototyping, testing and validating they come back to these strategies and in the iterative process of design study multiple bio-inspired 'move' techniques. Figure 4 shows a generic engineering design process that incorporates bio-inspired design.

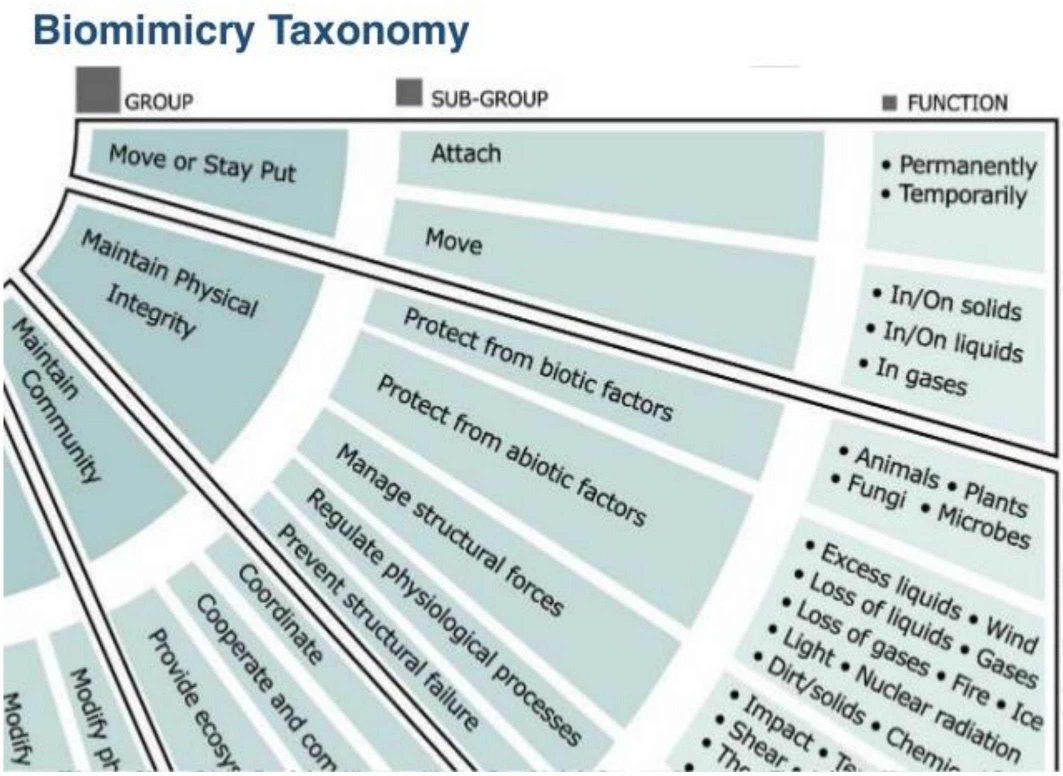

Figure 2 Biomimicry Taxonomy, Biomimicry Institute CC BY-NC 3.0 (detail)

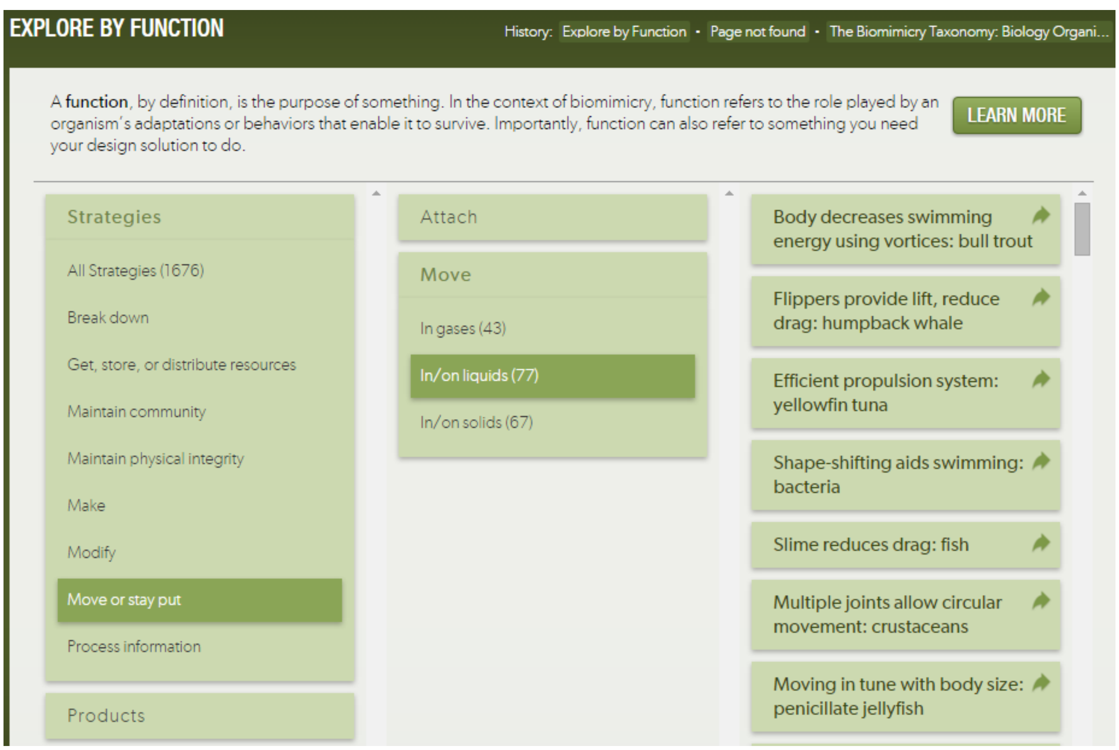

Figure 3 Search results on asknature.org for 'Move - In/on Liquids'

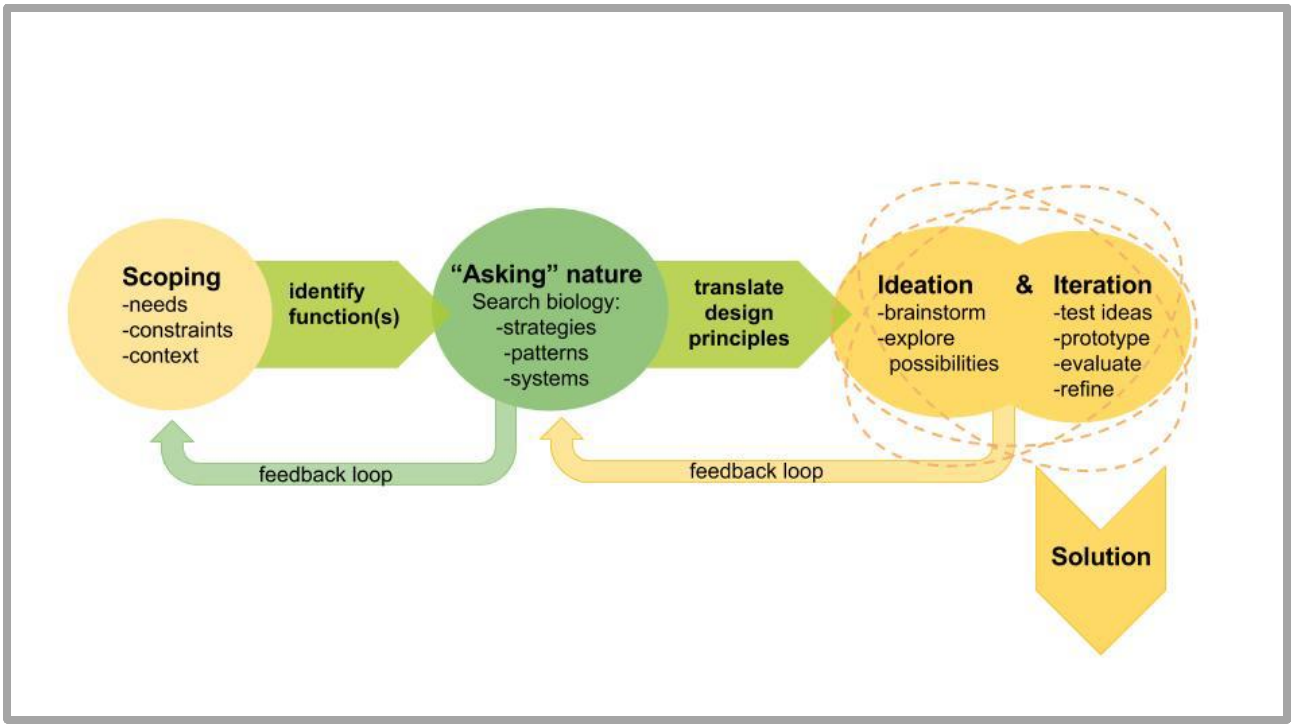

Figure 4 Bio-inspired engineering design process. Draft graphic courtesy of the Biomimicry Institute.

In September of 2015 as part of a city-wide art, science and engineering festival – Beakerhead (http://beakerhead.com/) - students at our school had an opportunity to see a presentation by, and interact with, the German industrial control and automation company Festo. Festo has a research lab, the Bionic Learning Network, which explores nature to change and improve the design of their technical products. Students were given a demonstration of their BionicOpter[3] (Fig. 5) and we, as the teaching team, followed up with a bio-inspired design project.

Figure 5 Festo's BionicOpter[4]

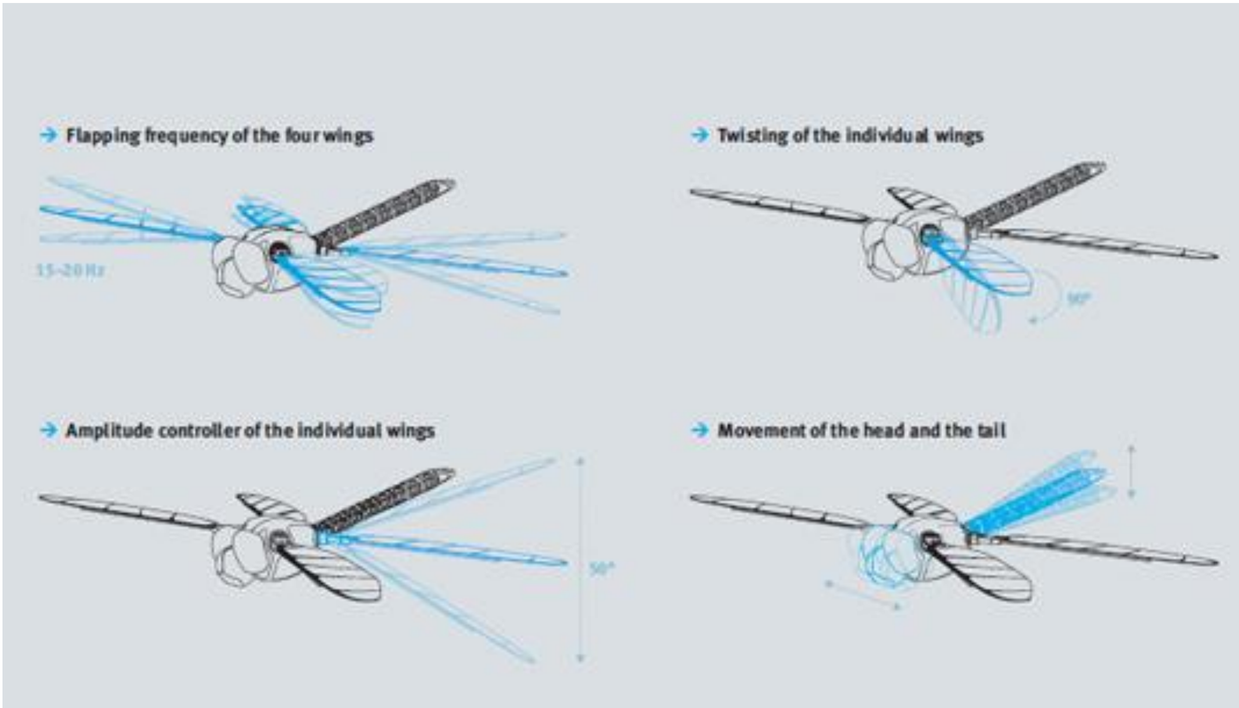

Figure 6 Festo's BionicOpter details[4]

The project was to design and build a biomimetic device that travelled through water. Each team was assessed on:

• The ability of their device to utilize a biomimetic means of propulsion to traverse a water trough;

• The communication of the team's design process, including: development and analysis of alternative solutions, prototyping, and testing.

At the start of this two-week project students in teams of four built a simple biomimetic flying device which used two lightweight 3D printed parts (Fig. 7) ('How to' video link: https://vimeo.com/139669835). It is an example of bio-inspired design, uses an elastic band as a power source, and uses a mechanism to convert rotational motion, to reciprocal motion, which then flaps the wings. The biomimetic features are the flapping of the wings and the shape of the flying device.

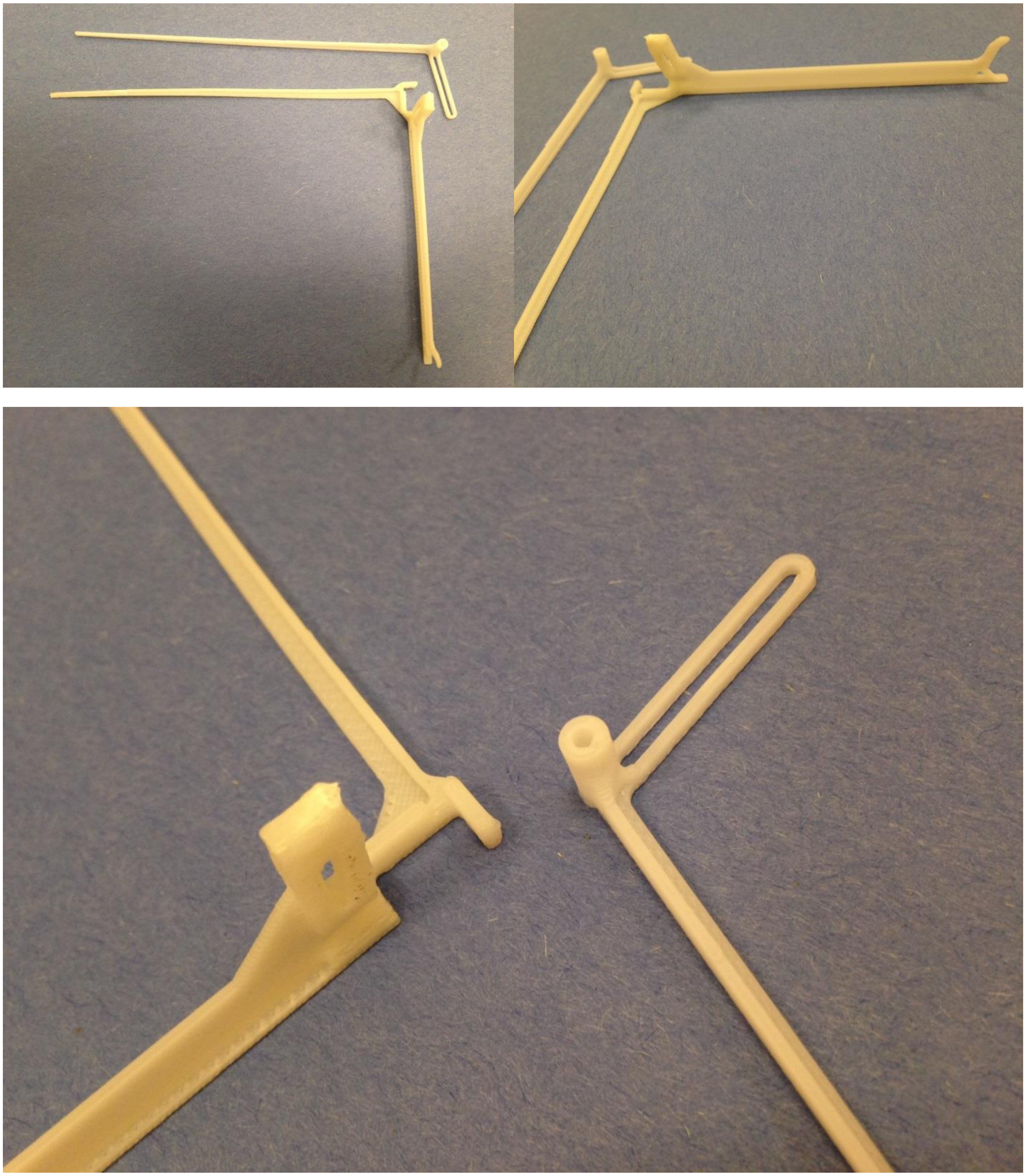

Figure 7 3D printed parts for the bio-inspired flyer

The water locomotion device was only required to demonstrate a biomimetic means of propulsion. We were more interested in function i.e. the mechanism than in shape i.e. the form. This did not mean we didn't end up with devices looking like ducks, bacterial flagella and sperm (Fig. 8), but we expected a certain amount of 'form follows function'- type water craft.

We asked for simple materials to be used, and did not allow pre-made devices or components (e.g. a toy fish). There was no limit on the use of recycled materials, but students were limited to a total team expenditure of $10 for the project.

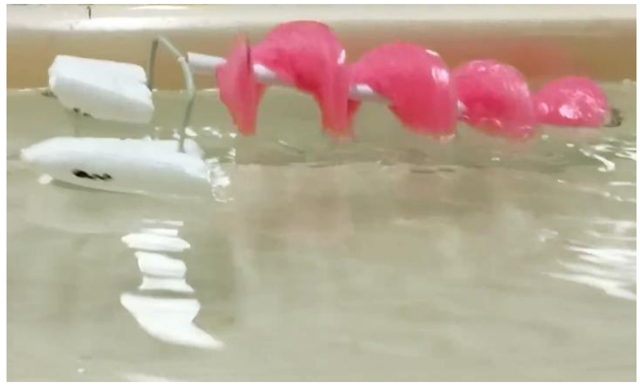

Figure 8: Bio-inspired water locomotion device based on sperm by Aaron Chau, Branden Shin, Joel Kramer, Vlad Timofyeyev

The final devices were judged during performance testing at the end of the second three-hour lab period. Each device was assessed on its ability to traverse a water trough available in each lab room. The device was placed at one end, behind a start line, 30 cm from the end to then be released by the team, and the maximum distance reached when the device stopped was graded. A maximum grade was given, if the device touched the far end of the water trough.

A wide variety of design ideas and implementations were generated by the students, including variations on:

- Water balloons, mimicking a squid or octopus
- Paddling mechanisms, mimicking water fowl, eels, amphibians, whales, and fish
- Screws, mimicking flagella

Video examples of some of the devices can be found here: https://www.facebook.com/SchulichEngineering/posts/973060979406502 and here: https://www.youtube.com/watch?v=COZJKPUL_HQ&feature=youtu.be.

Our first year design and communications course has a long history of bio-inspired design projects, but these were mainly paper-based. For those interested: an archive of examples can be found here: http://issuu.com/eggermont/docs/bio_drawing_sample

What has been new in the past two years is the hands-on nature of the projects and with it an increase in student enthusiasm and engagement.

3.0 Lessons Learned

To help ensure the biomimetic means of propulsion was used by the students, restrictions were placed so that they were not tempted to use more conventional means, such as "paddle-wheels," which were specifically disallowed. However, a minority of teams did use paddle-wheels, and attempted to make their device appear biologically inspired, for example, as a bear or a swan. These designs were penalized for deviating from our project requirements.

From a student survey at the end of the term, the feedback suggested that the students did not have enough time to complete this project to their satisfaction and they suggested to add one week to it, making the biomimetic watercraft project two weeks long (i.e. three lab periods). In a future iteration of the course, we would follow this advice to extend the time frame and this would allow us to check and redirect any teams that are not following the biomimetic guidance.

To add a sustainability component to the project, we encouraged the use of recycled and repurposed materials. In this spirit, we allowed the biomimetic flyer, or any of its parts, to be reused in the watercraft. However, one team found that the flyer, when submersed, could traverse the water trough, with no modification, and thus, become a trivial solution. We immediately disallowed the use of the flyer in the watercraft.

4.0 Conclusion

One of the key features of a design course is that students study subjects in breadth rather than in depth. In studying a wide variety of subjects, design courses employ a wider variety of specialists and this facilitates a cross-linking of cultures and perspectives. The conjoining of previously unrelated ideas, thoughts and concepts is well recognized as a feature of creative thinking. Introducing a full range of subjects allows students to practice and develop their integrative skills.[5] Biomimicry and bio-inspired design are integrative by nature and a valuable design tool for engineering students. We hope this project inspired other educators who are looking to incorporate this field into the engineering design curriculum.

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