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Pigs in Space: A Bio-Inspired Design and Space Challenges Cornerstone Project

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Abstract

On August 2-4, 2016, the Ohio Aerospace Institute (OAI) and Great Lakes Biomimicry (GLBio), in collaboration with NASA, presented the first annual National Biomimicry Summit and Education Forum for Aerospace. The overall Summit Objective was to establish a convergence of practitioners, disciplines, bio-inspired philosophy, tools and research for the benefit of all.

The Summit introduced VIBE (Virtual Interchange for Bio-inspired Exploration), a multidisciplinary team established by the NASA Glenn Research Center with the goal of creating a sustainable, cross-geographical, 24x7 online workspace. With biomimicry as its driving philosophy, VIBE seeks to advance biomimicry research in cooperation with partners from academia, industry and other government agencies.

A design project was created based on the themes explored during the summit and asked 880 students in a first-year engineering design and communication course to explore design inspired by nature and how it might benefit the following areas that were the focus of the summit.

1. Materials and structures for extreme environments
2. Persistence of life in extreme environments
3. Guidance, navigation and communication
4. Next generation aeronautics and in-space propulsion
5. Sustainable energy conversion and power

These areas are focus areas of NASA and of space exploration in general. This paper will describe the design methodology and approaches used for this project, report on the outcomes, and discuss lessons learned.

1.0 Introduction

Propulsion and power systems have made large strides over the past centuries leading to more efficient jet engines and solar electric propulsion to enable a journey to Mars. However, we are now faced with the limits of humans understanding of the physical world. The solutions we seek are more multidimensional, multifunctional and increasingly focused on the interaction of systems and their environment. Nonlinear multifunctional systems that have a symbiotic relationship with their environment are the domain of nature. Therefore, it is in nature that we seek inspiration for the solutions to tomorrow's challenges.

Our first-year design and communications course is a requirement for all incoming engineering students before they choose their preferred department in year two of their program. The course introduces students to teamwork, hands on design projects and individual paper based design projects such as the one we will be describing here.

After attending the Biomimicry Summit mentioned above a ‘design inspired by nature’ paper-based project was included in the Fall 2016 offering of the first-year design course. In engineering education there is an increase in bio-inspired design projects both for corner and capstone design courses.[1,2,3] Bio-inspired design projects allow for a great deal of creativity and enhance students’ ability to design by analogy. It also opens up a new design space as many solutions found in nature do not follow conventional engineering design practices.

Students were asked to follow a design process (Fig. 1) to complete the 5 stages of their project.

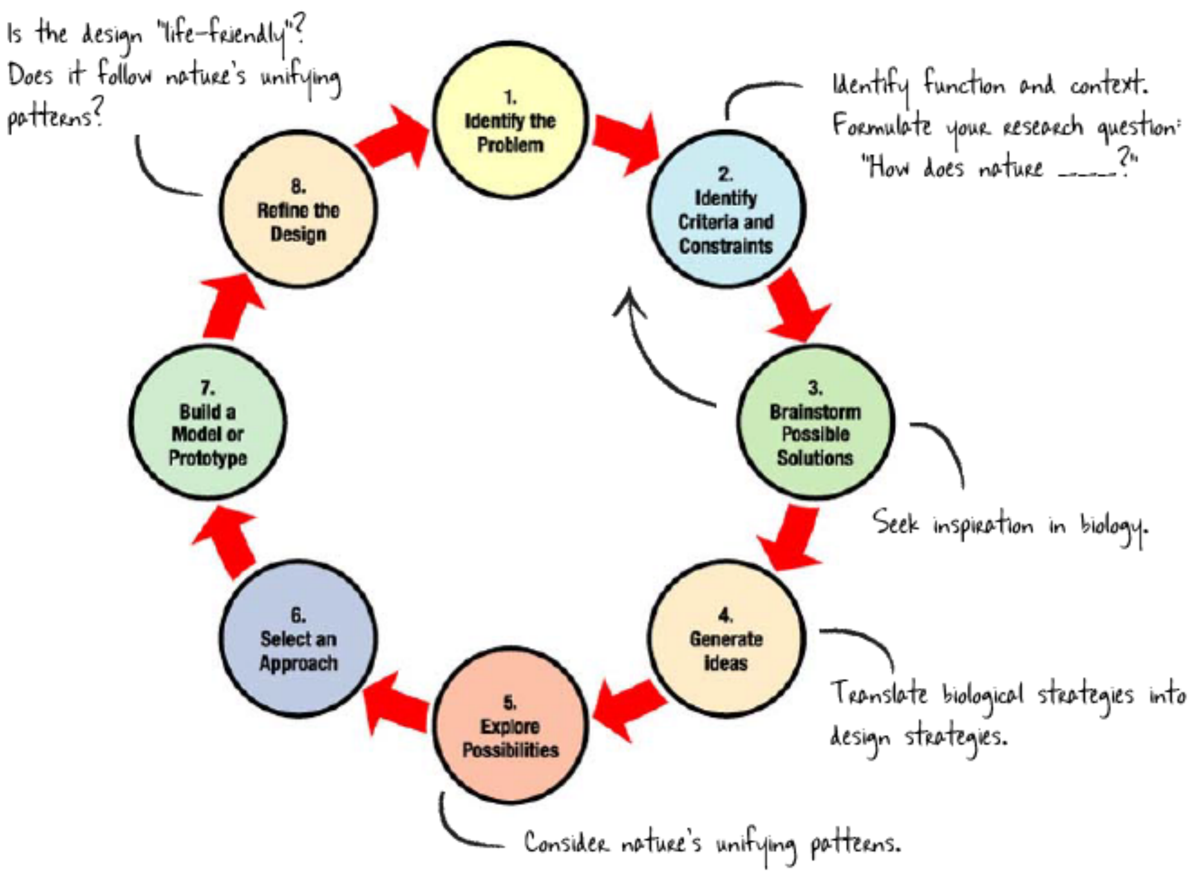

Figure 1 Modified NASA diagram to illustrate how biomimicry concepts can be integrated.

1. Identifying the problem/criteria and constraints: Researching NASA challenges,
2. Identifying criteria and constraints/Brainstorming solutions: Exploring Ask Nature,
3. Generate Ideas/Explore possibilities: Creating a challenges and strategies diagram,
4. Explore possibilities/Select an approach: Using the diagram to create an

illustration,
5. Model/Refine the design: Designing and drawing a bio-inspired design solution.

In the following sections these five areas will be discussed and illustrated with student work.

2.0 NASA challenges

In this first part of the project students were asked to research challenges (or opportunities) NASA and other space agencies are exploring and to narrow their search to three areas of interest. Figure 2 summarizes the most popular topics students explored.

Figure 2 Most popular student research topics for challenges

'Radiation' was the largest area of interest and 'Living on Mars' was a close second. Students summarized their findings and were introduced to IEEE citation style for referencing – one of the course learning objectives.

Based on their findings in this section of the project students then went on to ask the question: "How does nature…?" Based on figure 2 above questions would range from "How does nature handle radiation?", "How does nature repel dust?", "How does nature survive in extreme environments?", and so on.

A hypothesis of this design project is that students will be able to discover multidisciplinary solutions that are motivated by nature and that incorporate elements of natural principles such as feedback loops, multifunctionality, water based chemistry. In order to assess the success or failure of this approach a comparison between existing solutions to a problem and the bio-inspired solution can be made. For example, using the figure below as a qualitative measure and asking whether the solution defined by the student(s) satisfies one or more of the characteristics in the diagram of figure 3.

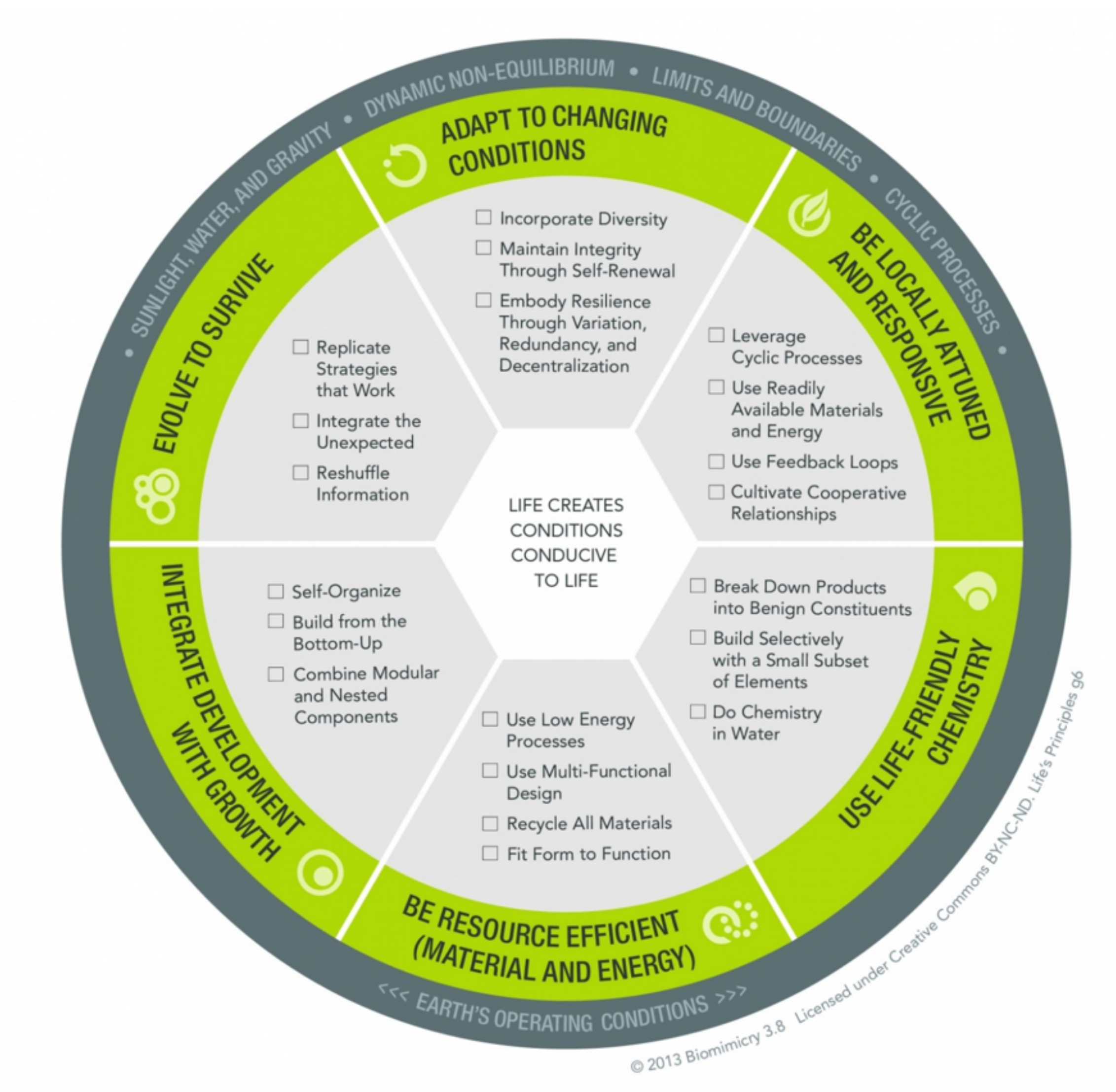

Figure 3. Characteristics of a successful natural system [Biomimicry 3.8]

3.0 Ask Nature strategy research

AskNature (http://www.asknature.org/) is a comprehensive catalog of nature's solutions to human design challenges. This online library features summaries of more than 1,800 natural phenomena and hundreds of bio-inspired applications both in the design and in the product phase.[4] AskNature can be explored by function asking the questions: "What does the design have to do? What are the functional requirements?"

Students were asked to create five summaries of five different organisms that were relevant in function to the NASA challenges picked in section 1. Figure 3 shows a summary of the organisms that were picked out of this resource of roughly 1,800 strategies.

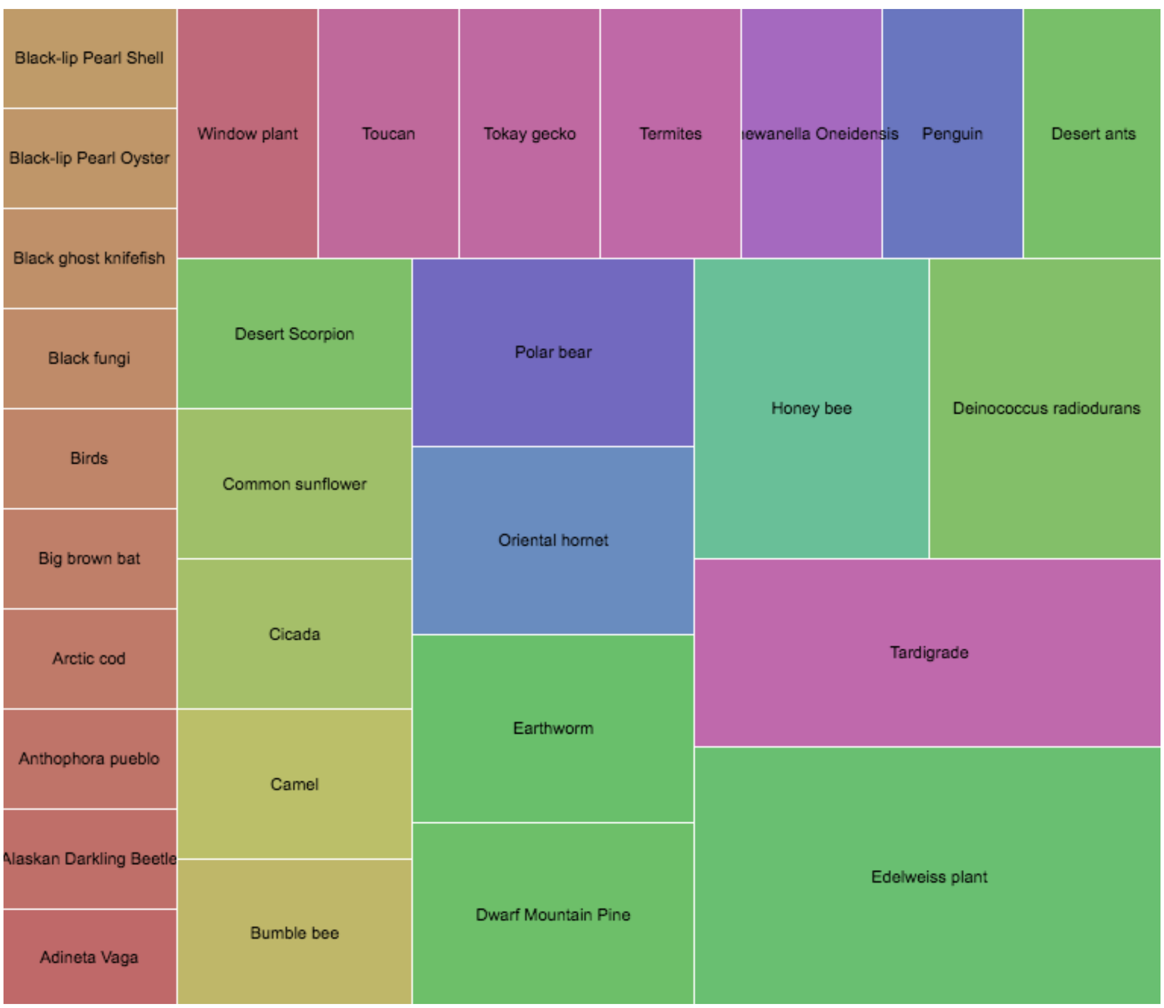

Figure 4 Ask Nature strategy research summary

Favorites were the wooly hairs of the alpine edelweiss that protect the plant's cells from ultraviolet radiation by acting as photonic structures that interact with and absorb the UV radiation.[5] The tardigrade was no surprise with its inspiring ability to survives extreme environmental conditions by entering a reversible suspended metabolic state known as cryptobiosis.[6]

Students are provided with the following aspects when reading Ask Nature strategies:

- The organism and often classification
- The abstracted function useful for finding design solutions
- The biological strategy usually a summary of primary research
- The design principle
- The mechanism (if definable)
- Possible application ideas
- Applicable life's principles (for a full list please see: https://biomimicry.net/the-buzz/resources/designlens-lifes-principles/)

Below are some student examples of 'design principle' drawings. These can be a key step in abstracting functionality and give the student an initial idea of where their design might be headed.

Figures 4 – 6 are the design principle sketches of an orbweaver spider, a sleeping chironomid, and holy basil. The student chose these particular organisms in the hopes of coming up with design solutions for his chosen challenges: *dehydration and the absence of water* and *prevention of radiation effects and damages*.

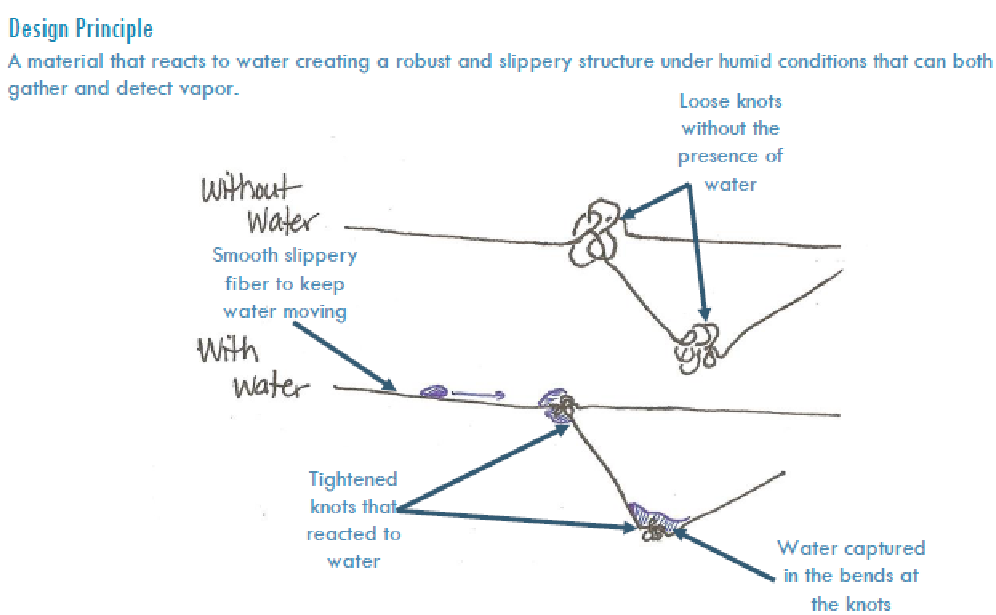

Figure 5 Design principle sketch Orbweaver Spider: collecting and capturing liquids from the air

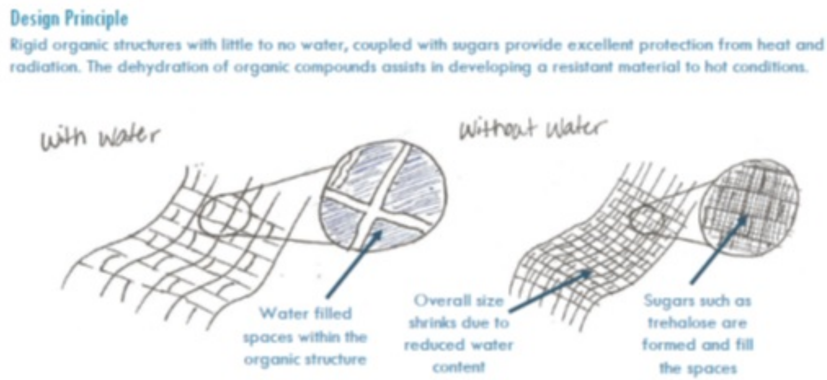

Figure 6 Design principle sketch Sleeping Chironomid: surviving desiccation from arid weather

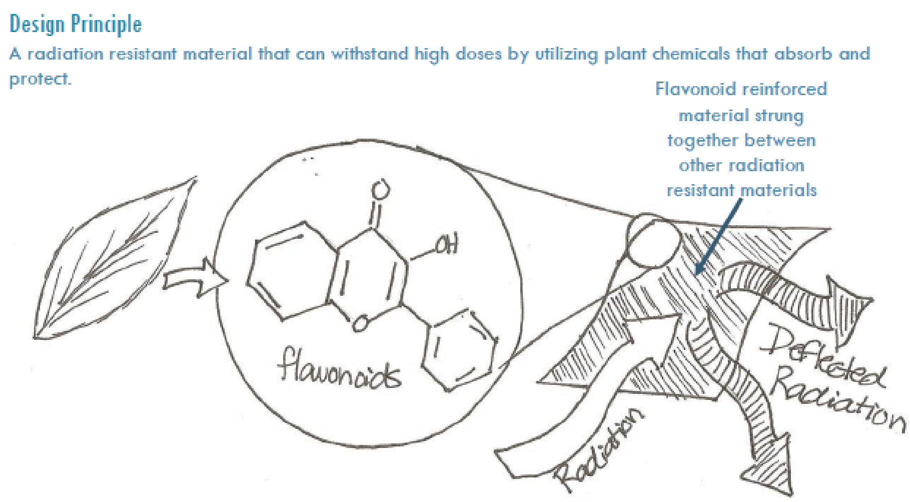

Figure 7 Design principle sketch Holy Basil: protecting against radiation and reduce damage done to DNA

4.0 Challenges and strategies diagrams

At this stage of the project students were asked to focus on the most promising and interesting strategy they had found on Ask Nature. They were asked to create a challenges and strategies diagram for one organism to see if they could come up with multiple design solutions. The challenges in this case focused on the challenges a particular organism is facing and how it solves them. Strategies can fall into three categories:

1. Form-based: shapes and patterns
2. Process-based: a series of actions that work together

3. System-based: a series of interacting elements or organisms that work together

Below are two examples. The first is a diagram for the dwarf mountain pine. The dwarf mountain pine's outer layer is covered in a wax, made from chromophores which absorbs the harmful UV-A and UV-B radiation.[7] Dwarf mountain pine cuticular wax contains fluorophores, a fluorescent chemical that emits light when excited. When the UV rays are absorbed it changes their wavelength and emits blue light which can be used for photosynthesis in lowlight conditions. This gives them an edge to other alpine organisms.[8]

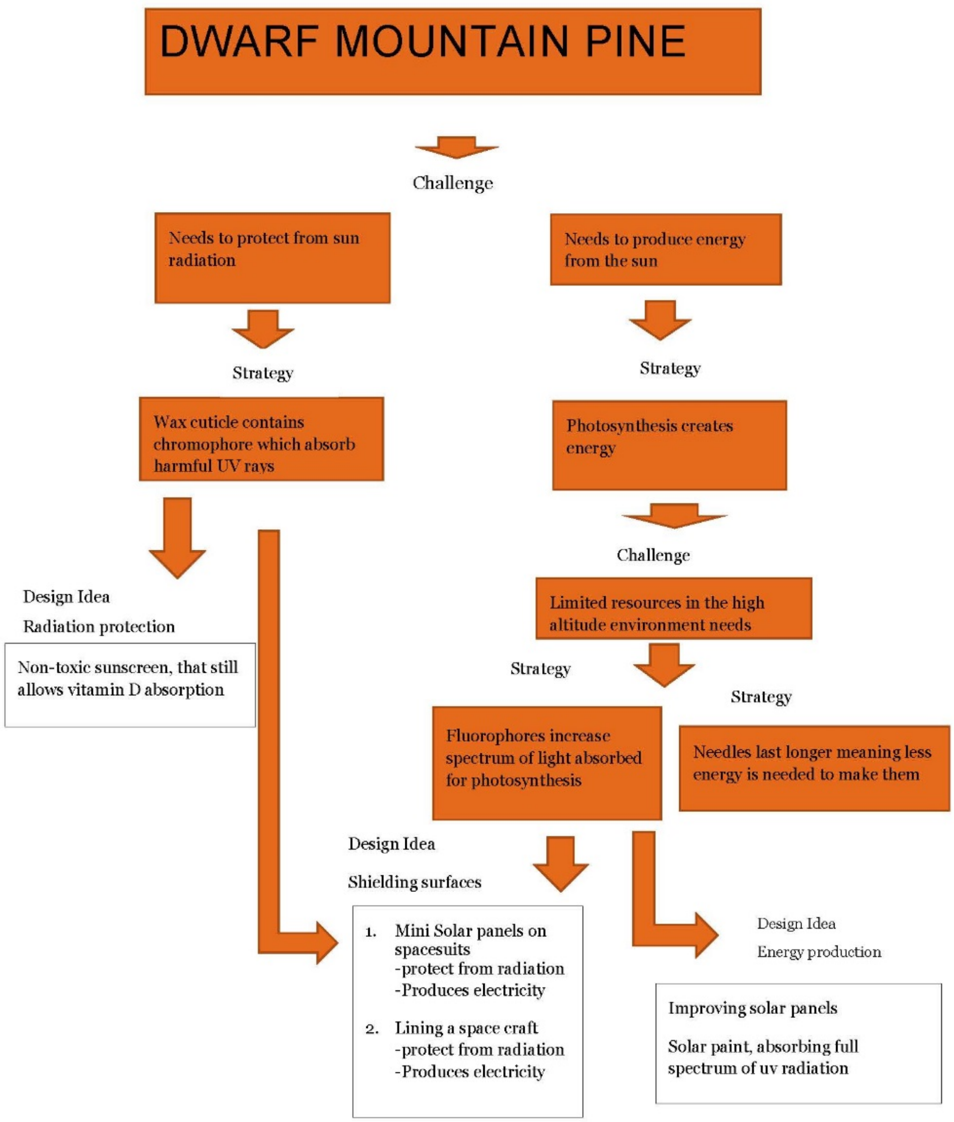

Figure 8 Dwarf Mountain Pine Challenges and Strategies diagram

The second diagramming example is that of the Cicada. The wings of Cicadas shed dirt and water while inducing a self-cleaning effect to prevent contamination, erosion, and bacterial accumulation. The biological structure of these wings also creates an anti-reflective coating. Wings contain thousands of hexagonal sections across the surface. These sections have nipple-like protrusions that hold air pockets between them to prevent the build-up/accumulation of bacteria, residue, and matter.[9]

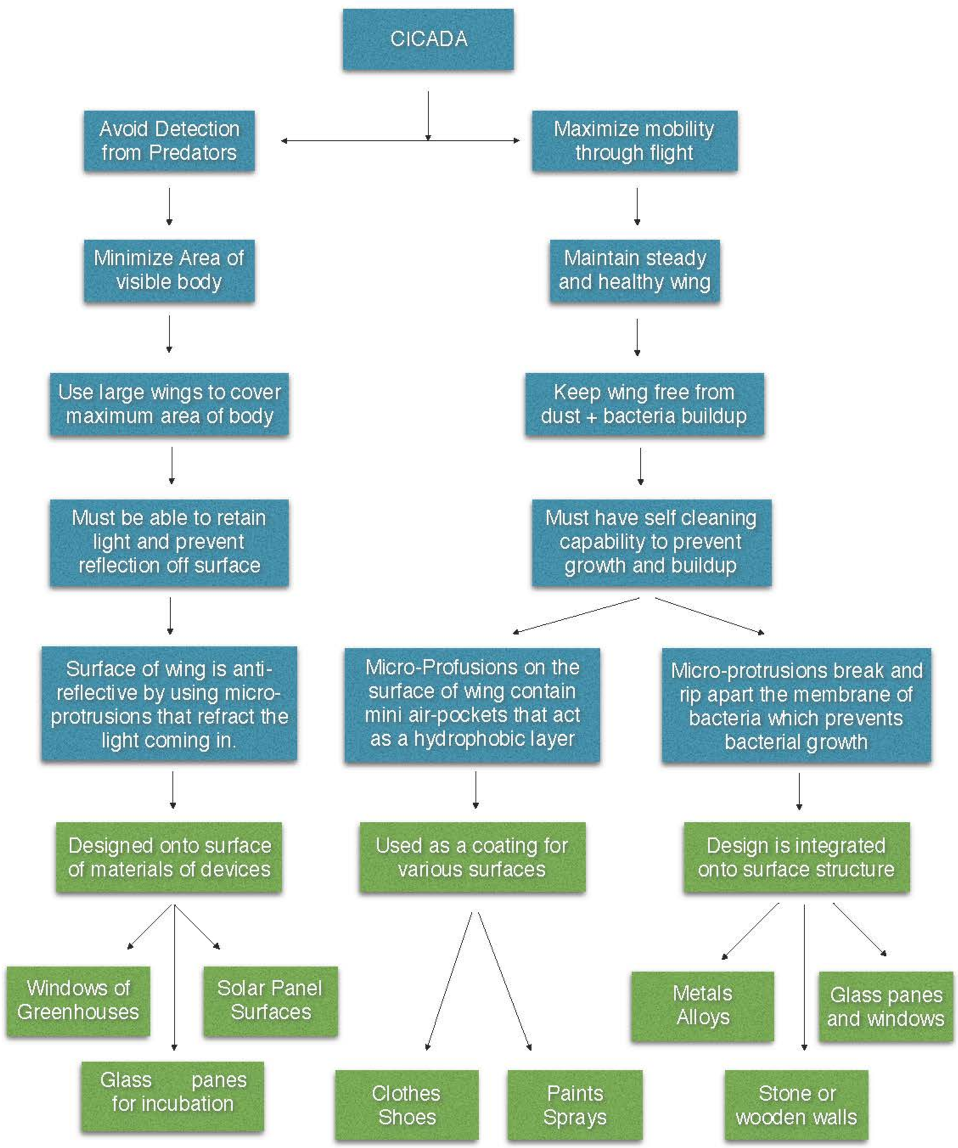

Figure 9 Cicada Challenges and Strategies diagram

5.0 Strategies illustration

Students in this course are often asked to visualize the strategies they have discovered. As an example, they are shown the work of Fritz Kahn (http://www.fritz-kahn.com/gallery/) well known for his metaphorical illustrations. He explained complex natural and technical principles with visual and textual analogies. He is considered a pioneer of infographics. *How something works* is a challenge to draw visually but the Kahn work gives students a sense of what is expected. Below are some student examples. The first illustration shows a Black-lip Pearl Oyster filtering seawater for plankton and assembling platelets that make up the structured layer of nacre on the inside of the shell.

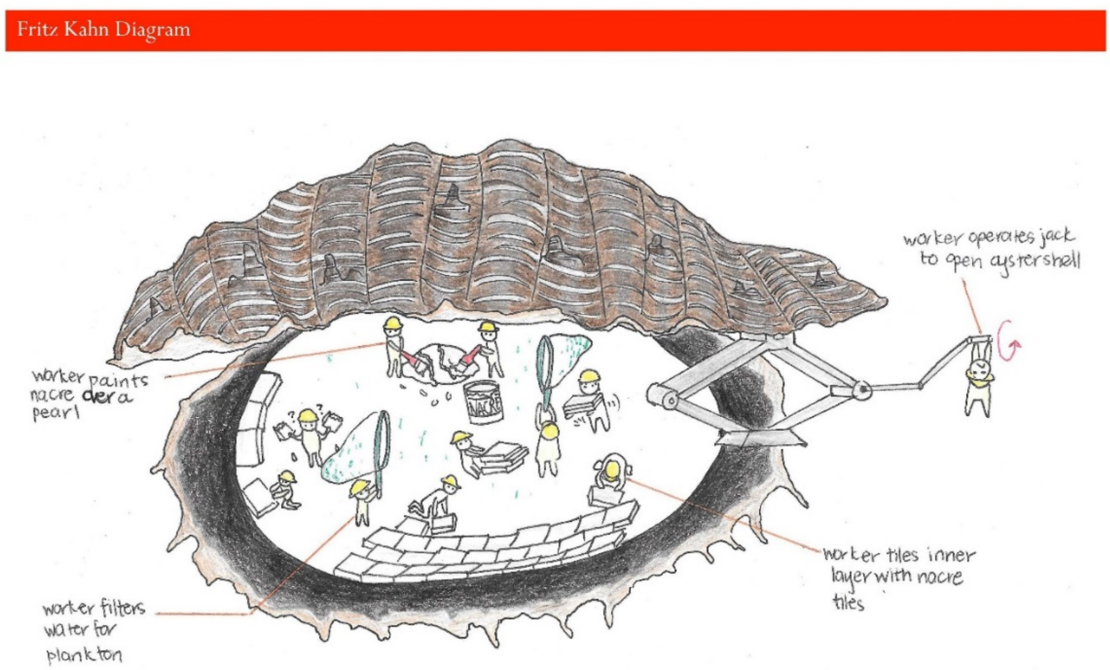

Figure 10 Fritz Kahn inspired strategy illustration of a Black-lip Pearl Oyster

The second illustration shows a Monarch butterfly with three of its strategies. Its accurate perception of position due to almost 360-degree vision, its high maneuverability, and its bright colors which indicate 'I'm difficult to catch' and 'I taste bad'.

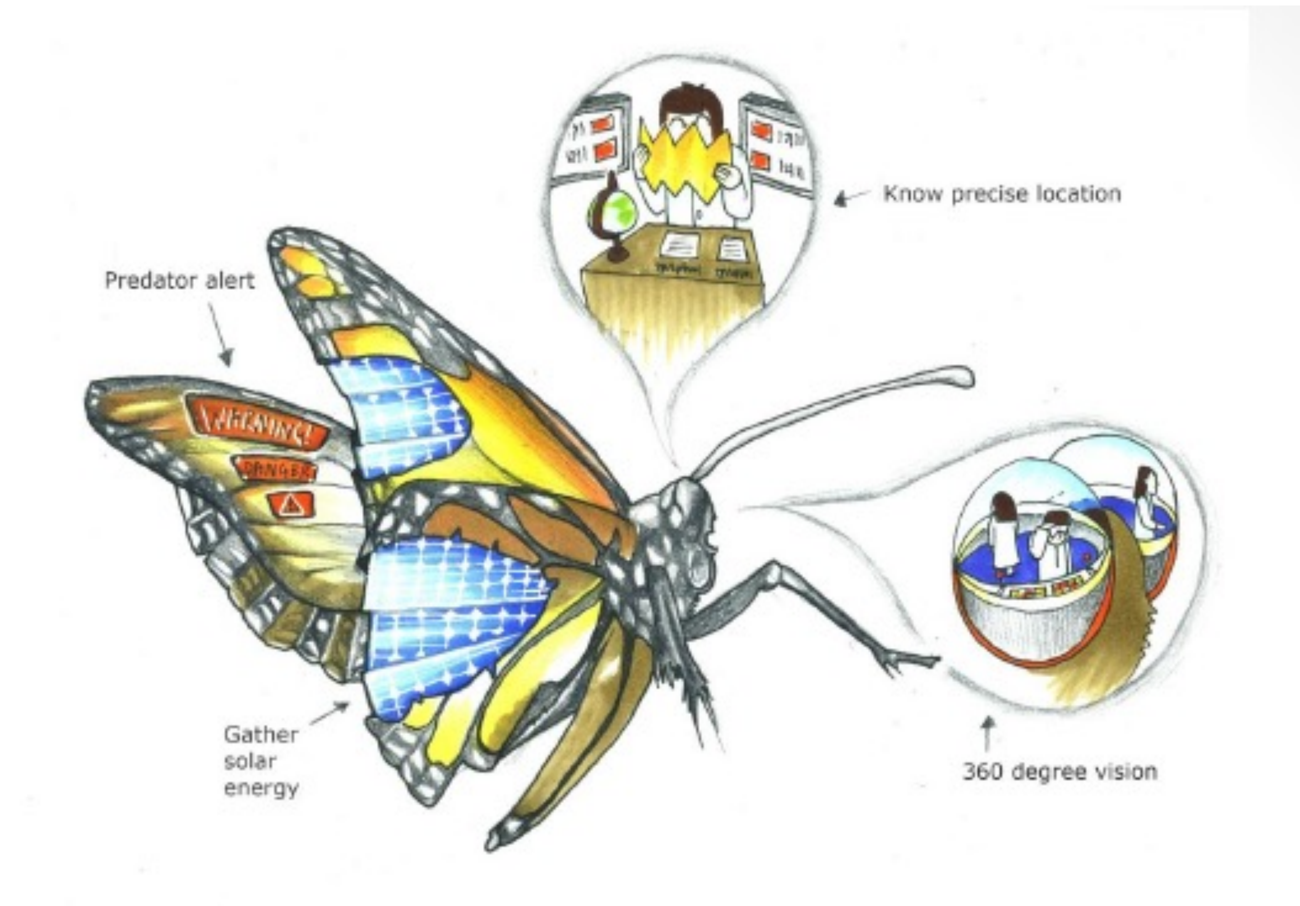

Figure 11 Fritz Kahn inspired strategy illustration of a Monarch butterfly

The third is an illustration interpreting the Many-Headed Slime or Slime Mould (*Physarum Polycephalum*). Slime mould has been an inspiration for optimization algorithms and in experiments researchers have had slime mould design an optimal rail system for Tokyo, "optimum transport networks of numerous cities as well as the Silk Road."[10]

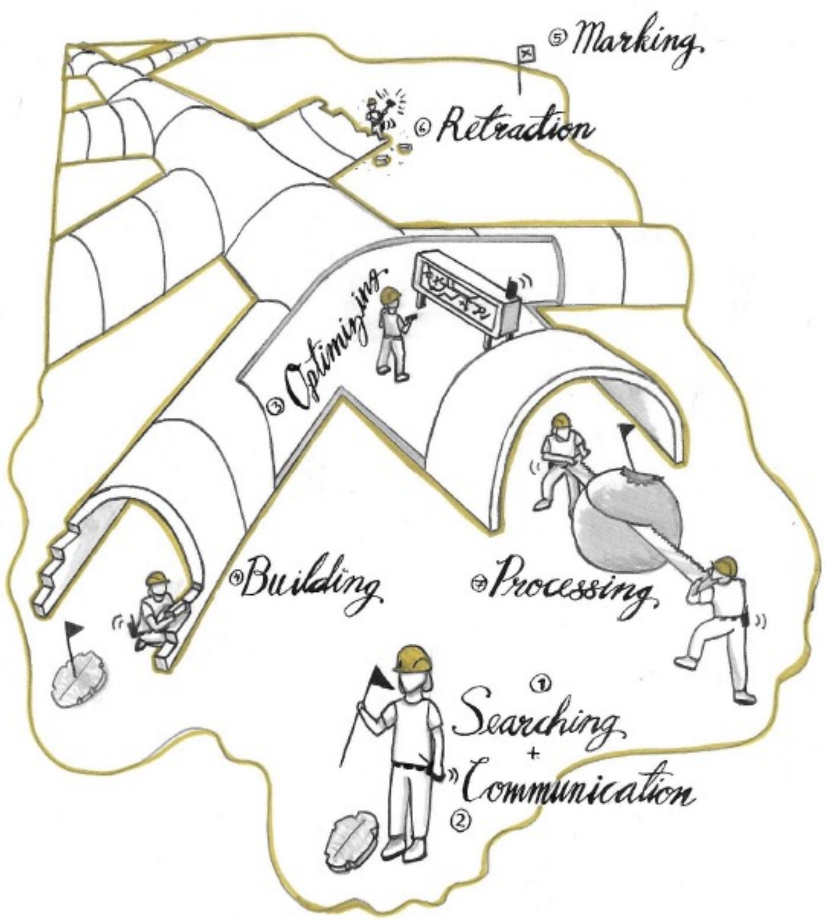

Figure 12 Fritz Kahn inspired strategy illustration of Physarum Polycephalum

6.0 Designing and drawing the bio-inspired design solution

For the final stage of the project students were asked to put all their work together and come up with anything from a subcomponent to an entire system and the design should ideally be of benefit to challenges in space and to challenges here on Earth. If the design was for an extreme environment, students had to try and think of how the design could be applied in an extreme environment here on earth. Below are three student examples. As can be noted from the drawings, materials and surfaces are prevalent and this was a theme throughout the final design work. Often in introductory biomimicry projects 'form-based strategies - shapes and patterns' and most popular with students and easiest to understand.

Final Design

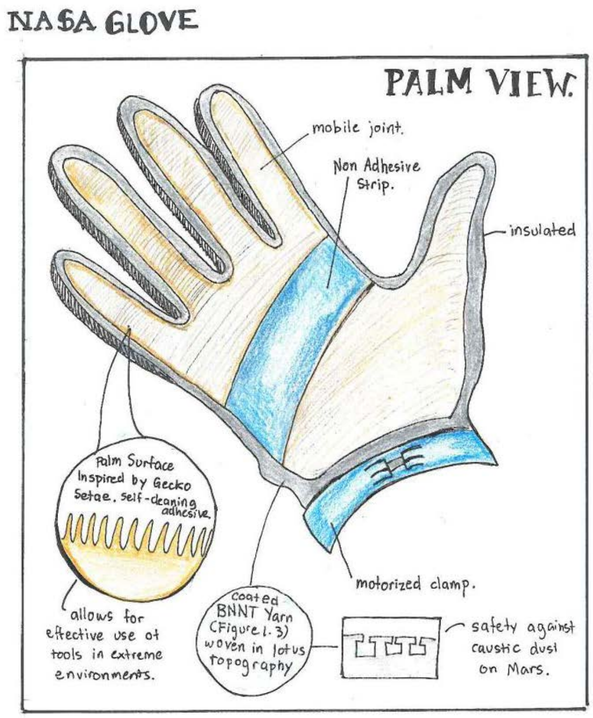

Figure 13 Final design space glove

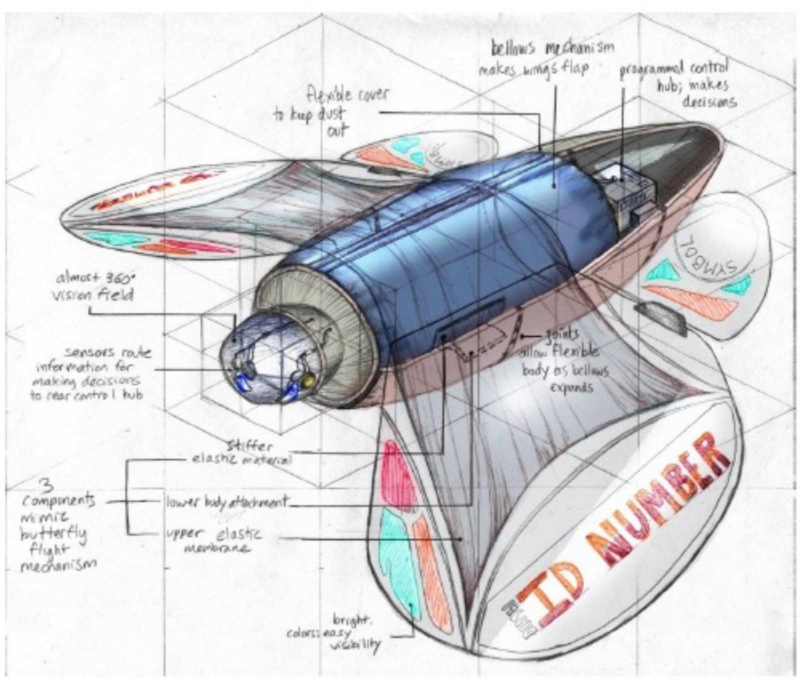

Figure 14 Final design space craft

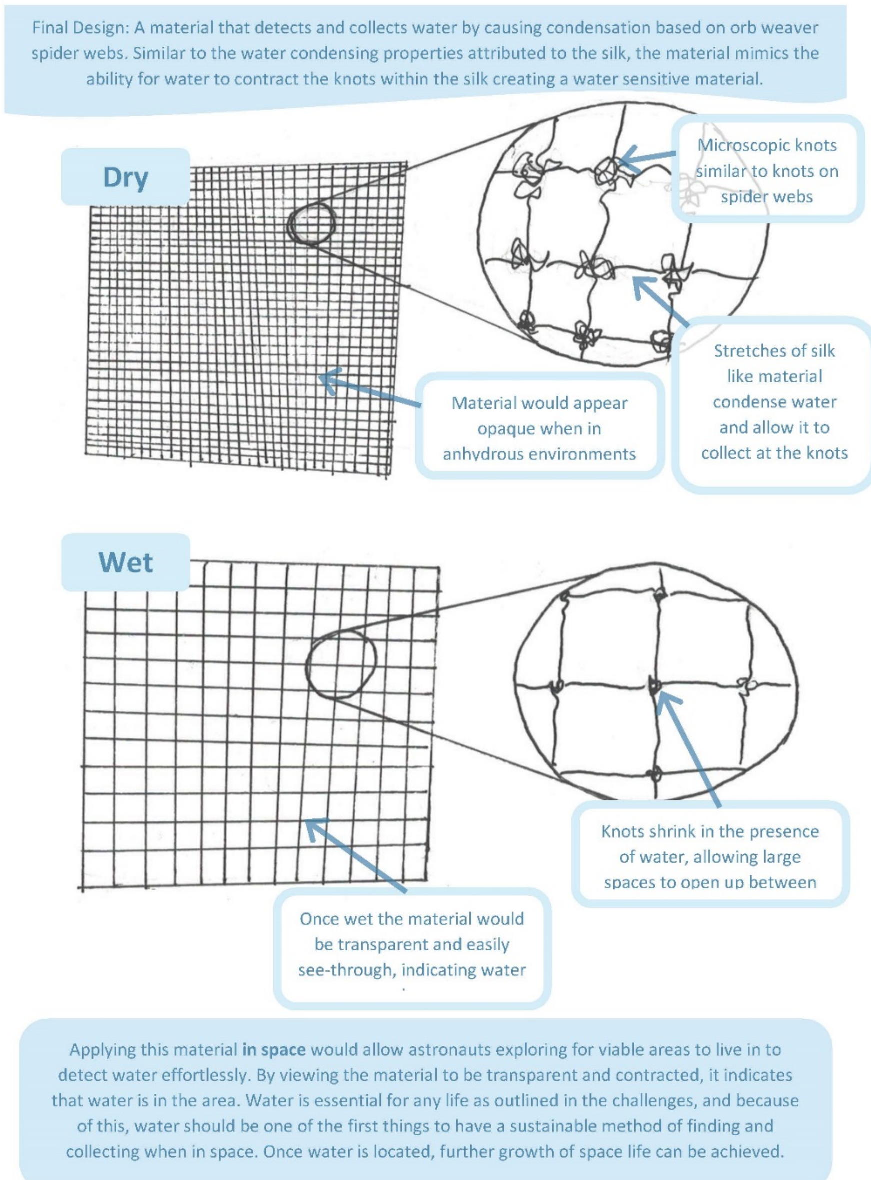

Figure 15 Final design material capturing moisture

7.0 Conclusion

In Fall of 2016 students in The Schulich School of Engineering at the University of Calgary were given an individual bio-inspired design project. The project was given out at the beginning of term and the final project was due three month later at the end of term. 880 students ended up submitting the project. Based on the word cloud of all projects below this group suggest we take a closer look at the edelweiss plant, the tardigrade, the dwarf mountain pine, earthworms and *deinococcus radiodurans* for our future in space.

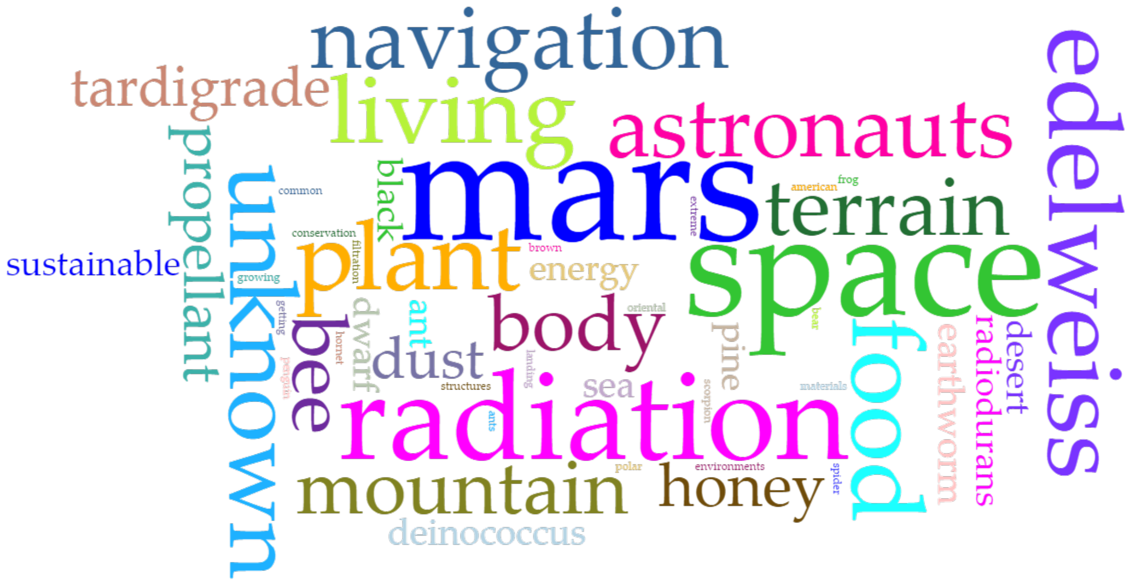

Figure 16 Word cloud of terms found most frequently in final projects

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