# INSPIRING ENGINEERING IN THE K12:

# BIOMIMICRY AS A BRIDGE BETWEEN MATH AND BIOLOGY


Fredrik Sanne

Inge Risheim

Thomas J. Impelluso


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Fredrik Sanne
Inge Risheim
Thomas J. Impelluso

Department of Mechanical- and Marine Engineering
Western Norway University of Applied Sciences
NO-5063 Bergen, Norway

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Høgskulen på Vestlandet
Fakultet for Ingeniør- og Naturvitskap
Institutt for maskin- og marinfag
Inndalsveien 28
NO-5063 Bergen, Norge



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| Author(s), student number: | Fredrik Sanne, h148896<br>Inge Risheim<br>Thomas J. Impelluso |
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| Contact person: | Inge Risheim |
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**Fredrik Sanne**
Western Norway University of Applied Sciences
(HVL), Bergen, Norway
fredriksanne1994@gmail.com

**Inge Risheim**
St. Paul Skole
Christiesgt. 16, 5015
Bergen, Norway
ingri@stpaul.no

**Thomas J. Impelluso**
Western Norway University of Applied Sciences
(HVL), Bergen, Norway
tjm@hvl.no

## ABSTRACT

The discipline of biomimicry encourages engineers to take design inspiration from the nearly four billion years of research and development since life first appeared on Earth—nature is the greatest engineering designer. Rather than leveraging biomimicry as a discipline unto itself (a worthy approach, regardless), this project explores biomimicry as a tool to inspire K12 students to appreciate math and engineering. We conducted this project in four lesson modules and one lab. In the first module, we presented various types of engineering. In the second, we introduced certain aspects of mathematics from a qualitative perspective. In the third, we discussed the fundamental mathematics that undergirds thermodynamics, although qualitatively and visually. In the fourth, we introduced the students to the world of biomimicry. Then we integrated the mathematics and biomimicry with a laboratory experience in quantitative design, borrowed from an NSF sponsored project. In summary, efforts in biomimicry reside at either the quantitative arena of multi-phase physics, or the qualitative arena of biological interpretations. However, we have use it as a bridge to science, math and engineering.

## NOMENCLATURE

| | |
|---|---|
| $T$ | Temperature |
| $k$ | Heat capacity |
| $F$ | Force |
| $m$ | Mass |
| $a$ | Acceleration |
| $q$ | Rate of heat transfer |
| $h$ | Heat transfer coefficient |
| $A$ | Surface area |
| $\alpha$ | Absorptivity |
| $\sigma$ | Stefan-Boltzmann constant |

## INTRODUCTION

The UN presents 17 Sustainable Development Goals as a transformative global roadmap for national and international efforts aimed at eradicating extreme poverty while protecting planetary boundaries and promoting prosperity, peace and justice. The Norwegian government desires to enrich high school education with an integrated vision of goals. This project introduces two of these 17 goals (quality education and sustainable cities and communities) by leveraging the discipline of biomimicry.

Innovation derives from generating new engineering designs. Job opportunities in STEM fields are thus, growing faster than in non-STEM fields [1]. Despite this, interest in engineering continues to decline [2, 3]. Various countries are attempting interventions to encourage interest in Engineering in the K12 [4]. This project attempts to straddle the goals of securing interest in STEM, sustainable design, and respect for the mathematics needed in STEM fields.

### Math and engineering

Students leave engineering because they see it as "a learning environment that fails to motivate them and is unwelcoming [5].". The literature also reports that students leave engineering due to "experiencing conceptual difficulties with their courses [6].". The literature is not specific on the nature of these conceptual difficulties. Finally, women are 1.5 times more likely to leave the science and engineering pipeline, *after calculus*, compared to men [7].

In the sophomore year, students must rise above foundational and motivational courses—introduction to engineering, calculus, physics, etc.—and confront *gateway* courses that enable the transition into the major. These gateway courses—dynamics, fluids, thermal science—*realize* the mathematics students have learned. Students with visualization ability overcome these limits through independent extensions, excursions and explorations; other students simply drop out.

**Biomimicry**

Biomimicry is the study of nature's unifying patterns and strategies, and how we might extract and use them to optimize inventions, interventions and designs [8].

As one well-known example of biomimicry, we recall the Kingfisher bird and its role in the design of the bullet trains. The bullet trains operating in Japan induced shock waves when exiting tunnels. The train's high speed and the sudden change in air pressure when exiting a tunnel induced a sonic boom that propagated for miles. To address this challenge, in addition to modeling solid/fluid interaction mathematics and software, one of the engineers working on the project turned to his hobby as a bird watcher. He took inspiration from the kingfisher bird's head and beak, motivated by the fact that the Kingfisher bird dives straight into the water with an accompanying change in the density of the surrounding medium (much like the bullet train exiting the tunnel). The engineer designed the nose of the train to resemble that of the Kingfisher bird. This reduced the sonic boom and the train ran 10% faster with 15% better power efficiency [9].

One may suggest that this particular engineering analysis lies in the domain of multi-phase physics (e.g., solid/fluid interactions). In fact, one might assert that the discipline of biomimicry is a facet of multi-phase physics but qualitative in nature. Currently, biomimicry serves instructional inspiration for qualitative engineering.

> "*Though human genius in its various inventions with various instruments may answer the same end, it will never find an invention more beautiful or more simple or direct than nature. Because in her inventions nothing is lacking and nothing superfluous.*"
>
> *Leonardo da Vinci*

In this project, we used biomimicry as a tool—not for of design, but for inspiring students to learn. We endeavored to show high school students the significance of mathematics by focusing on nature. Mathematics tends to become more abstract, and this makes students lose interest. By bridging the gap between biology and mathematics and giving purpose to math (regardless of how it may be distilled or simplified), the students will see mathematics as something within their grasp.

## THESIS FOR THIS WORK

The main thesis of our work is that biomimicry can serve to bridge the disciplines of biology and engineering, and that this will inspire students to study math.

A related, but minor thesis is that schools must take care when presenting issues such as global warming. In particular, in our module, we spend time discussing one such aspect of global warming: the conversion of radiation wavelength by the earth. With this in mind (as presented herein), the second thesis of our work is to *encourage* doubt in global warming by highlighting this issue. We feel it is an error to entrench sustainability issues in science such as chemistry and math, when the student is not yet ready for those advanced concepts. Students should be given the freedom to doubt; and perhaps they will, in the process, gain conviction.

## DEPLOYMENT SITE

**St. Paul's Catholic School** is a Catholic primary and lower secondary school in Bergen, Norway. It was established in 1873. About 340 students attend the school from first to tenth grade.

The students for this discussion are aged 13-14, and come from an eight-grade class, with widely distributed interest for math in particular and science in general. The school teaches the same curriculum as the state-owned public schools in Norway. However, time was taken from the curriculum for this project. The reason this school was chosen is a coincidence resulting from the fact that no public school that the authors contacted were interested.

The students had already been the taught basic "pre-calculus" (e.g., simple algebra and geometry). In two years, they shall decide direction for their further studies in college.

The goal of this project is to stir the interest in them for engineering and practical problem solving along with inspiring them to choose a scientific direction.

> *"Mechanical science is the most noble and useful beyond all others, since by means of it, all animated bodies that have motion perform their operations."*
>
> *Leonardo da Vinci*

We provided four modules, partitioned into two lectures. We now discuss these modules, except for the engineering module that consisted of a summary of the main types of engineering.

During the delivery of the modules, we referenced the thoughts of da Vinci and, later, Feynman.

## MODULE 2: MATH

While the reader of this paper is well aware of the math discussed herein, we present an overview of our math presentation to underscore how we qualitatively presented the math as a prelude to the physics, biomimicry, and the lab.

### Integral Calculus

We commenced our intervention with a disruption. As the students were preparing for the first lecture, we asked them to guess how many jellybeans they thought two different jars contained. The same jars contained different sized candy. We recorded the guesses.

**Figure 1: Jellybeans in a jar**

Then we discussed how to approximate the volume of the jar in "units of jellybeans." We asked them to count how many across the bottom and how many along the side. Then they used the volume formula of a cylinder to obtain the result.

We discussed with the students that this task manifests the *integral* calculus. We discussed how the smaller the unit jellybean, the better the approximation—how the volume is integrated from the tiny particles.

### Differential Calculus

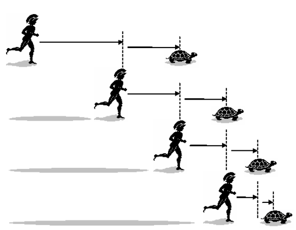


**Figure 2: Achilles and the tortoise**

We discussed Zeno's paradox. Zeno, a pre-Socratic philosopher in the fifth century BC, challenged logic by proposing the following paradox. The runner, Achilles had a race with a tortoise, which had a head start and which moved at half the speed of Achilles. Achilles runs a certain distance to catch up, but in that time, the tortoise moves ahead again, by half. Once again, Achilles moves further, but the tortoise moves ahead again by half that distance. This analysis suggests Achilles will never catch the tortoise.

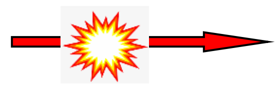
We discussed how geometry is an essential aspect of the paradox.

To understand this paradox, we discussed the average speed at any given moment during this logical process.

$$\bar{v}_{average} = \frac{\Delta x}{\Delta t}$$

Thus, we introduce the idea of measuring the average speed during shorter and shorter time intervals and arriving at a new number. We used pictures. In this way, we suggested the differential calculus as an "exhilarating" way of doing math at the infinitely small or large.

$$\lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \longrightarrow \frac{dx}{dt} = velocity$$



We summarized with an example by working out the derivative of $x(t) = t^2$. We avoided theoretical complexities, make it fun, and limit the discussion only to convey the idea.

$$\text{Rate of Change} = \frac{\text{Change of x}}{\text{Change of t}} = \frac{(t+\Delta t)^2 - (t)^2}{\Delta t}$$

$$velocity = \quad = \lim_{\Delta t \to 0}\left(\frac{(t+\Delta t)^2 - (t)^2}{\Delta t}\right)$$

We did this without any of the associated baggage of the calculus.

We concluded with another question that reveals the enigmatic nature of space: A person leaves his house and walks 1 kilometer south, then 1 kilometer east, then one kilometer north. He is back home. How is this possible? He lives at the North Pole and space is curved.

We ensconced this within an overly simplified few of the foundation of three aspects of math. The goal here is to continue the act of categorizing—avoiding quantitative analyses and focusing on qualitative discussion for inspiration.

**Table 1: Simplified Categories of Math**

| Math | Focus |
|---|---|
| Geometry | Study of space |
| Algebra | Study of numbers and operations |
| Calculus | Study of change |

### Summary

We asked them to recount the number of jellybeans in each jar. Their guesses vastly improved, but more so for the jar with the smaller jellybeans.

## MODULE 3: HEAT

While the reader of this paper is aware of the physics discussed herein, we present the outline of our presentation to underscore how we taught the physics qualitatively, and how we integrated the physics into the biomimicry, the math and the lab. We also recognized the ambiguity of the definition of the word energy.

> *"It is important to realize that in physics today, we have no knowledge of what energy is. We do not have a picture that energy comes in little blobs of a definite amount. It is not that way. However, there are formulas for calculating some numerical quantity, and when we add it all together it gives "28"—always the same number. It is an abstract thing in that it does not tell us the mechanism or the reasons for the various formulas."*
>
> *Richard Feynman*

For our needs, we defined Energy as "some measure" of the vibration of molecules in a body. We discussed how someone falling from a greater high, has more energy. We let *q* "represent" the vibration of the molecules.

We defined heat as the transmission of energy from a higher temperature to a lower temperature, and symbolize it with "*q*."

As Norway pushes sustainability studies, it is possible that students are left bereft of a complete understanding of energy. It is possible that this lack of completeness confounds them in their scientific understanding, and, perhaps fosters a desire to "memorize" science. Yes, there does exist solar energy, kinetic energy, mechanical energy, wave energy—however these exist as a group of mathematical terms that conserve certain quantities (and which can be used to power machines); these are terms that result from the mathematics that we "wrap" around our observations of the physical world. Any "feeling" the student has, that such terms carry some ambiguity, is something that should be encouraged, not denied. The students may memorize the terms, but they should be informed that there does remain some ambiguity and it does not arise from their own lack of comprehension.

### Overview of heat transfer from a qualitative perspective

Categorization is fundamental to science. We presented the categories of heat exchange, without reference to heat or math:

- Things happen.
- Things happen from a short distance and from a long distance.
- However, we can further break down the short category. From a short distance, things can happen by direct contact between solids or without direct contact.

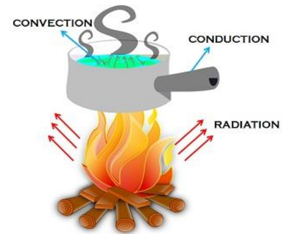



**Figure 3: Heat Transfer Summary**

**Table 2: Categories for Heat Transfer**

| Things happen | Heat flows |
|---|---|
| Things happen from a long distance | Radiation |
| Things happen from a short distance, between solids | Conduction |
| Things happen from a short distance, between solids and fluids | Convection |

Thus, conduction and radiation are fundamental physical mechanisms: these are the only two; however, the first can be sub-categorized. Again, the goal here is simplicity and categorization without the math.

Conduction is by touching (hand touching hot stove) and while radiation is from a distance (face looking at the sun). Convection is like conduction; however, convection happens with surrounding fluids.

### Conduction

Conduction is the movement of heat or electricity by direct contact. It usually happens between solids, e.g.; iron and shirt.

### Conduction Mathematics

$$q = (kA)\frac{dT}{dx}$$

This equation asserts that the heat exchange, q, is a function of a constant, the area in contact, and the change of temperature across the distance. We had no desire to expound on the math, except to reference the elements of the equation.

### Conduction Discussion

We asked the students to imagine placing one end of a metallic stick over a fire and sense the changing temperature in their hand. We left this as a qualitative experience but made sure to link it to the equation's parameters.

**Convection**

Convection is the transfer of heat by the hotter material *moving* into a cooler area. It usually happens between a solid and a fluid (water, or air).

A heater inside the balloon heats the air and so the air moves upward. This causes the balloon to rise because the hot air gets trapped inside.

**Convection Mathematics**

We presented this equation but simplified its discussion to its qualitative nature.

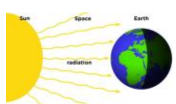
$$q = (hA)(T_1 - T_2)$$

This equation asserts that the heat exchange, q, is a function of a constant, the area in contact, and difference of temperature between the solid and the surrounding fluid. We had no desire to expound on the math, except to reference the elements of the equation.

**Convection Discussion**

We ask the students to go outside and feel the cold Norwegian air. Then we ask them to run for a short distance. We ask them if they felt colder. We explained that as they run, they strip away the warm air near their face and they feel colder.

**Radiation**




Radiation refers to energy that travels through space or matter in the form of energetic waves or particles.

**Radiation Mathematics**

$$q = (\sigma A)T^4$$

Here, we simply referenced that this equation consisted of a power term. We had no desire to expound on the math, except to reference the elements of the equation.

**Radiation Discussion**

Radiation induces the hot feeling when you stand *beside* a campfire. However, if you put your hand above a campfire, it's even hotter because then you not only have heating by radiation, but also by convection.

A vacuum flask, or thermos flask, uses our understanding of radiation (and heat transfer in general) to keep your soup warm. We all know that light bounces off mirrors, but all electromagnetic waves tend to bounce off reflective surfaces. Thus, the mirrored surface of a vacuum flask does a great job of stopping heat loss by radiation. A vacuum flask also stops conduction by having a vacuum layer—conduction needs a material to travel through and convection by having an insulating lid.

**General Discussion**

At this point, we compare the distinctions in the three laws

**Table 3: Categories for Heat Transfer**

| Category | Similarity | Differences | Math |
|---|---|---|---|
| **Convection** | $hA$ | $(T_{stop} - T_{start})$ | Algebra |
| **Conduction** | $kA$ | $\frac{dT}{dt}$ | Calculus |
| **Radiation** | $\sigma A$ | $T^4$ | Powers |

## MODULE 4: BIOMIMICRY

The lecture presented many examples of biomimicry: Velcro, shark skin swimming suits, owl feathers to muffle noise, the bullet train, lotus flower for self-cleaning surfaces, the Namib dessert beetle for self-watering greenhouses. However, we spent some additional time on the termite problem, which we summarize, next.

**Termites**

In Zimbabwe, termite colonies construct large mounds for their colonies. Inside the mounds, they farm a fungus that is their primary food source. The fungus flourishes at a constant temperature of 87 degrees F—it must be near constant. Meanwhile, the temperatures outside range from 35 degrees F at night to 104 degrees F during the day, when the sun is high (radiation). The termites must find a way to maintain a constant temperature inside the mounds.

The termites achieve this by constantly opening and closing a series of heating and cooling vents throughout the mound over the course of the day, when heat is absorbed through radiation (convection). This enables carefully adjusted convection currents. Air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. The industrious termites constantly dig new vents and plug up old ones in order to regulate the temperature [10].

**Eastgate Mall**

The Eastgate Center is in Harare, Zimbabwe. It was designed based on biomimicry principles. It has no conventional air-conditioning or heating. The temperature is regulated year-round with design principles based on the termite mounds. Outside air in drawn in from the bottom. It is warmed or cooled by the building itself (conduction and convection), depending on what is hotter: the building or the air outside. The air is then steered through channels, which open or close, before exiting at the top [11].

## LAB

Save the penguins curricula was developed by Christine G. Schnittka in cooperation with Auburn University, under the auspices of an NSF grant.

Since we are modifying the activity slightly, we renamed it to "Polar Bear Shelter," for the students in Norway.

We first present a summary for those not familiar with this pre-existing, innovative lab developed at Auburn.

Students are given an array of materials (cotton, paper, plastic, etc., each with its own cost). Students must purchase material and build a shelter. Inside the shelter, they will place an ice cube polar bear. A heat lamp will melt the polar bear shaped ice cube. The student task job is to delay the melting process by building a shelter containing materials of your choosing from a selection of given materials. However, the materials have a price tag and the students are given a budget. Throughout the melting period, the students will have had to weigh their polar bear ice cube several times. They will have had to write down the weight of the polar bear ice cube each time. The experiment will last for 20 minutes. Why are we doing this? To plot and figure out how *fast* the polar bear is melting and comparing your design to others." [12]. We did not discuss the concept of rate in mathematical detail but referenced the previous discussion on calculus and Tables 2 and 3.

By adding continuous weighting, we introduce the students to calculus. Calculus is the study of change; and this is essential for engineering calculations. Plotting numbers that one can see and understand makes the introduction to calculus intuitive and easy to grasp. The goal here was to distinguish all possible aspects of a successful design: not just which cube holds out the longest, but the rates of melting.

## FINAL DISCUSSION: GLOBAL WARMING

To understand global warming, there is one factor that the high school curriculum does not integrate well—rather it relegates it to memorization without comprehension. Incoming (short wave) radiation from the sun slips through the atmosphere (much like tiny particles passing through the fibers of a thick blanket). However, once the earth absorbs this energy, it will be emitted, but on the "earth's terms" as a different form of heat. This newly released form is at a longer wavelength than when it entered. Since it is "longer," the energy can no longer slip back out (through the fabric of the atmosphere). In essence, the earth "enlarges the wavelength of the heat."

The chemistry curriculum can explain how the atmosphere can let some energy pass, but the curriculum does not explain the change in wavelength. We feel it is extremely important to isolate this critical factor from the attempts to teach global warming in an otherwise reified discipline like chemistry or physics (simplified for the high school mind). We feel that this "conversion phenomena of the wavelength" relies on advanced physics. The average student embraces this by memorizing the phenomenon; and this, eventually, leads to doubt and skepticism. Students should be directly informed of this critical piece of information; and that it exists beyond the high school curriculum. Students must be given the freedom to doubt this and we should not fear the doubt; rather, it must be explained in the light, and students must be free to make up their own minds. Once this fact is isolated, we can then "surround" it with math and biology: we can motivate students to save the polar bears.

## CLOSE OF LECTURE

During the two lectures and the lab, the students ate the jellybeans. Later, we asked the students why the jellybeans had a crunch to them. Then we explained that all jellybeans are coated in the feces of insects. We had a great time.

Below, we present a summary of the student assessment of the count for the small jelly beans and the large ones, both before and after they appreciated the calculus. We present the average count of the students and the standard deviation.

| | **Before** | | **After** | | **True** |
|---|---|---|---|---|---|
| | Average | Std. dev | Average | Std. dev | |
| Small | 3232 | 2815 | 9605 | 821 | 9637 |
| Large | 313 | 235 | 565 | 86 | 510 |

We see an improvement in the guess after the students applied calculus to their guesses. However, there was a difference in the improvement between the larger and the smaller candies. Because of the larger size, the jellybeans were limited in the appliance of basic calculus. The smaller ones had less space around them, making that jar more amenable.

## ASSESMENT

**Likert Survey – On a scale from 1 (strongly disagree) to 5 (strongly agree)**

"**I know what biomimicry is**." Few students claimed to have heard of or knew anything about biomimicry in the first survey (2.5). After the experience, the students had more knowledge about what biomimicry is (3.9), especially considering the brevity of the presentation.

"**I think designs based on biomimicry will give me a simpler life.**" Most students answered neutral on this question in the first survey (3.2). Most students didn't know what biomimicry was and were not able to make a choice in either direction. After the experience, there were an increase in students thinking designs based on biomimicry will give them a simpler life (3.9).

"**I understand the science that explains global warming.**" – The first survey showed that most students consider themselves knowledgeable of the science behind global warming (4.3). After the experience, it had a slight increase (4.,6).

"**It is okay to be climate skeptic**" – There were a majority of students thinking it is okay to be climate skeptic (3.7). During the lecture, they were given the freedom to doubt while we also focused on the critical aspect of global warming that they do not have the full ability to comprehend. Then this number actually decreased (3.6).

"**I believe nature can help engineers with solutions to our problems**" – Most students were positive in believing nature could help engineers with solutions to our problems (4.0). After the experience, the students were more convinced about nature helping engineers (4.7).

"**I would like to study mathematics/mathematics-related subjects by secondary school**" – Eleven students answered 4 or 5 (3.0). After the second survey the number of students answering 4 or 5 decreased to 9, but more of the students answering 1 or 2 increased to 3 (3.2).

"**I would like to study to become an engineer after high school**" – Six students answered 4 or 5 (3.0). After the second survey the number of students answering 4 or 5 increased to 9 (3.1).

**Anecdotal Comments**

**After the Math Lecture**

- "I thought it was a good lecture. I learned a lot about things that I don't think we would have focused on in a regular lecture, and that was exciting. For example, Zeno's paradox. It was very interesting but a little complicated."
- "It was educational and exciting to get to know what an engineer does."
- "I thought the PowerPoint was good and I have now decided which type of engineer I want to be."

**After the Energy Lecture**

- "I learned a lot about energy and heat and how heat transfer works."
- "I thought it was really fun, educational and exciting. I would very much like to do something like that again."
- "It was also interesting to learn about conduction, convection and radiation."

**After the Lab**

- "I thought it was very fun to use my creativity to make an insulated house. We had to use our foreknowledge as well as draw and construct the structure."
- "It was great. A fun way to learn about heat and insulation. It gave me a little sneak peek into the work of an engineer."
- "It was very fun, and it was a great way to learn about engineering."

**SELF-ASSESSMENT**

The following are comments by the student-teacher who taught the classes and directed the lab, are presented in his words.

"The math lecture went off as expected. No issues. The comments are presented in the words of the student."

"The second day the lecture lasted for four hours in total. In thermodynamics we focused on heat transfer. By using practical examples and showing them videos, they roughly got the concept of heat transfer. We also specifically discussed the concept of insulation."

"Biomimicry was an unknown topic to the students. They were not aware that nature provides inspiration for our technology. By showing them examples from success stories within the world of biomimicry they managed to make connections between biology and engineering. I can tell the students seemed confused since they are not taught that biology and technology are related in the way they are. Technology and inventions are thought of as not deriving from nature."

"The last three hours of the lecture was all about the lab, "Polar bear shelter". They got divided into six groups of 4-5. Most of the students were very engaged in designing and building the shelter for the ice cubes. I overheard them discussing concepts of heat transfer and insulation in mind when they designed the shelter. The organization with the materials got a little messy after a while. I did not hand out the materials personally. Instead, the materials were placed on a table and they were responsible to get what they needed. I should have handed out the materials myself and kept track of what I gave to who."

"We had three weighing stations. The first groups to build their shelter began the heating process and weighing their ice cubes every two minutes for 20 minutes. Every group got a valid result. One group cheated and pushed their shelter out of the way from the heating lamp several times. They got disqualified. As of the rest of the groups, everyone got different results. One group ended up melting both of the ice cubes, and on the opposite, one group managed to keep almost half of the mass they started with."

## DISCUSSION OF RESULTS

Results indicate that such a module at the intersection of engineering, math and biomimicry does excite students to learn. It had positive affect on student understanding of the role of mathematics. It inspired some students to study engineering. It enabled them to see the value of sustainable engineering design.

In some cases, the positive results were relatively weak. However, we attribute that to our own inexperience. This is a learning process for us, and we seek input and advice from readers of this paper.

We should have directly asked the students how this could have been improved.

We were a bit disorganized on this first approach—too much freedom for students to walk around. In the next round, we will exert a bit more control.

We feel we targeted one grade level too low.

The first step of this project was to introduce a few students to the world of biomimicry by teaching in class and doing the polar bear shelter activity.

## FUTURE WORK

Next year, we will repeat this. However, we will also focus on Dynamics and the study of motion using an analysis of dragonflies. Within the world of engineering, the study of motion is essential. Newton's second law of motion states that an objects acceleration is dependent upon two variables: the mass of the object and the net force acting upon the object.

**Dragonflies**

One might think of lions as being the most successful predators in nature, but this is wrong. Lions catch between 20-30% of their prey. Dragonflies on the other hand, catch up to 95% of their prey. Many factors make the dragonfly one of the world's most deadly predator. Most significantly, it is the dragonfly brain and eye. It maintains the focus on one single target amongst hundreds of others while predicting where it is going. Getting to the target requires highly advanced maneuverability. The wings of a dragonfly are powered by individual muscles that work together for top of the line acceleration and agility, making it fairly easy to reach their target. The eyes of a dragonfly are highly advanced. They are designed to detect black spots against the sky, making it possible for them to single out one small target amongst several others [13]. Most surprising, is that the neural network of the dragonfly, enables it to fly not where the insect currently is, but where it will be. Does the dragonfly "calculate" kinematics of motion—and what would that mean?

This type of strategy and trait can be useful within aerospace. Drones has been made to mimic the dragonfly's flight, lowering power consumption for an increased range and to better tolerate wind and environmental conditions [14].

**Motivating Artificial Intelligence with Dragonflies**

The trait of predicting where an object is going to end up, in the near future was considered to be related to mammals, such as us humans [15]. Hitting the brim while shooting hoops can make the ball fly off in another direction, but even though the ball will take a path that was not intended we are most likely to predict where the ball will go. Imagine having hundreds of basketballs bouncing around in the same area and you were to keep track of one of them and predict which path it would take. This is very similar to how dragonflies would do it, only their target is able to move in any direction.

The way the dragonfly brain works is intriguing when it comes to further development of artificial control and vision systems.

In our next project, we will relate Newton's Laws, the kinematics of dragonflies, and the dynamics of Norwegian floating windmills.

## APPENDIX

**All questions on a 10-point Likert Scale**

**Diagnostic Evaluation Questions (before the class and lab)**

1. I know what Biomimicry is.
2. I think designs based on biomimicry will give me a simpler life.
3. I understand the science that explains global warming
4. It is okay to be "climate skeptic" (disagreeing that there is global warming).
5. I can do something to influence climate change in a direction I believe is right.
6. I believe nature can help engineers with solutions to our problems.
7. I would like to study mathematics / mathematics-related subjects by secondary school?
8. I would like to study to become an engineer after high school.

**Summative Evaluation Questions (after the class and lab)**

1. I know what Biomimicry is.
2. I think designs based on biomimicry will give me a simpler life.
3. I understand the science that explains global warming
4. It is okay to be "climate skeptic" (disagreeing that there is global warming).
5. I believe nature can help engineers with solutions to our problems.
6. I understand why we are learning math.
7. I would like to study mathematics / mathematics-related subjects by secondary school?
8. I would like to study to become an engineer after high school

Written statements after the experience.

1. What do you think of the first session in this project? (Stick to what is being said / shown and not the person who says / shows)
2. What do you think of the second session in this project? (Stick to what is being said / shown and not the person who says / shows).
3. What do you think of the lab in this project? (Stick to what is being said / shown and not the person who says / shows).

## REFERENCES


[1] GAO, "Science, Technology, Engineering, and Mathematics Trends and the Role of Federal Programs, statement of Cornelia M. Ashby, Director, Education, Workforce, and Income Security Issues.," *Accessible at http://www.gao.gov/new.items/d06702t.pdf,* 2006.

[2] N. S. Board, "Science and engineering indicators 2004," ed: NSB Publication No. NSB, 2004.

[3] “Committee on Prospering in the Global Economy of the 21st Century, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*,” ed: Washington, DC: National Academy of Sciences, 2007.

[4] (April 30, 2018). *Research Experiences for Teachers (RET) in Engineering and Computer Science*.

[5] American Society for Engineering Education. Creating a Culture for Scholarly and Systematic Innovation in Engineering Education. 2009. http://www.asee.org/about-us/the-organization/advisory-committees/CCSSIE

[6] Geisinger, B., and Raman, R., 2013, Why They Leave: Understanding Student Attrition from Engineering Majors. International Journal of Engineering Education. Vol. 29, No. 4, pp. 914–92.

[7] Ellis J, Fosdick BK, Rasmussen C (2016) Women 1.5 Times More Likely to Leave STEM Pipeline after Calculus. PLoS ONE 11(7): e0157447. doi:10.1371/journal.pone.0157447.

[8] Biomimicry Institute (2019, April 19). Retrieved from https://biomimicry.org/what-is-biomimicry/

[9] Vox (2019, March 4). Retrieved from https://www.youtube.com/watch?v=iMtXqTmfta0&t=44s

[10] Niki Wilson (2019, April 19). Retrieved from http://www.bbc.com/earth/story/20151210-why-termites-build-such-enormous-skyscrapers

[11] Jill Fehrenbacher (2019, April 19). Retrieved from https://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/

[12] Christine G. Schnittka (2019, March 4). Retrieved http://www.auburn.edu/~cgs0013/ETK/

[13] Ella Davies (2019, March 4). Retrieved from http://www.bbc.com/earth/story/20151222-which-animal-is-the-deadliest-hunter-on-the-planet

[14] Animal Dynamics (2019, March 4). Retrieved from https://www.animal-dynamics.com/project-details-1

[15] Steven D Wiederman (2019, March 4). Retrieved from https://phys.org/news/2017-07-dragonfly-brains-path-prey.html