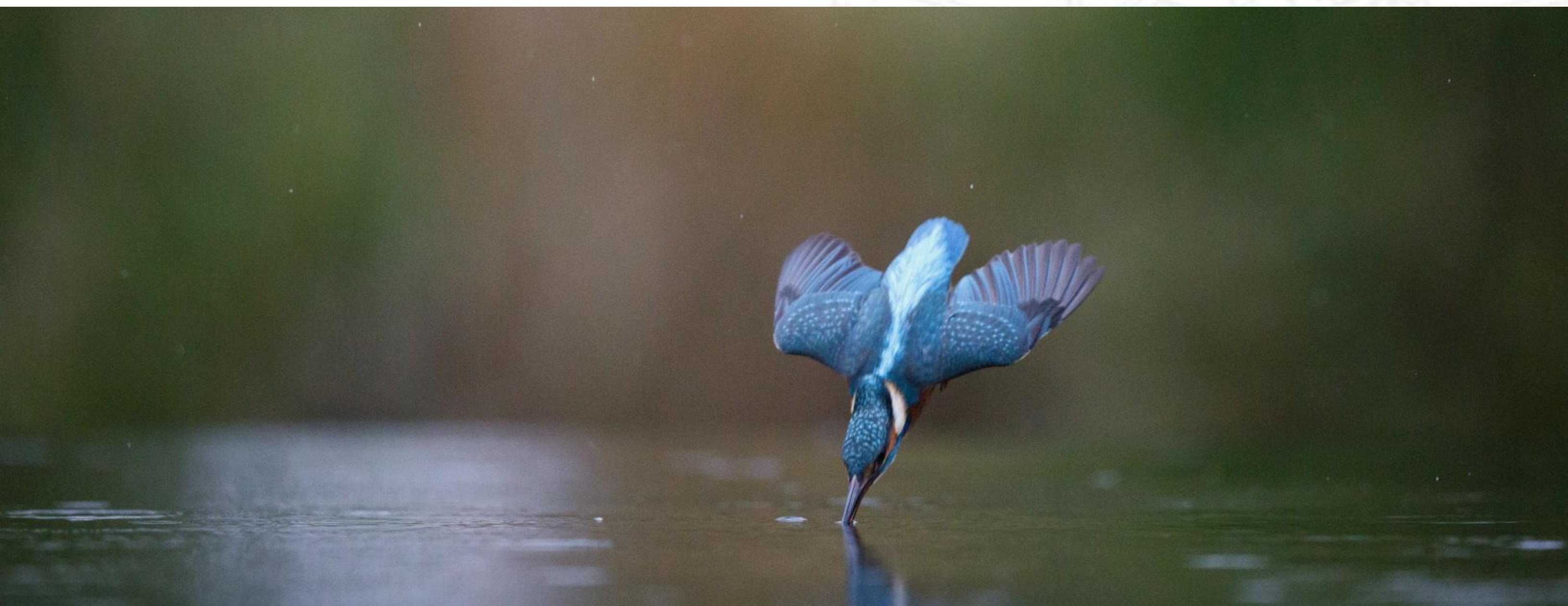
Engineering Inspired by Nature

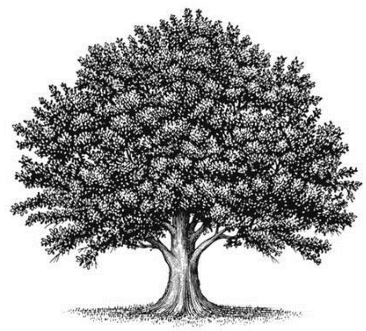
THE UPPER ELEMENTARY ENGINEERING DESIGN CURRICULUM



Invention Inspired by Nature's Genius

Designed for the NGSS

The Center for
Learning with Nature



Education should be a means to enriching individual lives and improving our world. The Center for Learning with Nature, a non-profit organization, is dedicated to this idea by integrating wonder and technological mentorship from the natural world into everyday school curricula. Our goal is to simultaneously build awe and capacity in students and teachers alike, through unique, exceptional curricula and teacher training.

Visit us online at www.LearningWithNature.org.

Acknowledgements

This work would not have been possible without the help and influence of many other people and organizations. I especially would like to thank my children, Julio and Kestrel, and my wife, Tammy. I would also like to thank Janine Benyus, who changed forever how I see the natural world and the possibility of a sustainable human way of life. I would also like to thank Education Outside, Doug Williams and Aimee Barber at the University of Louisiana, and many, many other educators too numerous to list. Finally, I'd like to thank the Board of Directors of The Center for Learning with Nature, the United Engineering Foundation, Cynthia Loebig of the Kalliopeia Foundation, and the Clif Bar Family Foundation.

Feedback on the *Engineering Inspired by Nature* curriculum:

"The nature-inspired engineering unit was just what my students and I needed to take our STEM class to the next level. By looking to nature for ideas to solve human challenges, we are able to not only do our STEM work but also connect with the natural world which is exactly where we want our students to be. The material is a perfect match for my nature based STEM classes which feed into the NGSS engineering standards for our students' report cards. I am thrilled to have the resources provided by The Center for Learning with Nature and I am excited to share them with more STEM teachers in our area."

Jodi Sikma, Hamilton Elementary School, Hamilton, MI

"One of the most important skills students can learn to prepare them for the world is to ask their own questions. We know students are engaged in important curriculum when what they are doing in school mirrors what professionals would be doing in the workplace. The Engineering Inspired by Nature unit allowed my fifth-grade students to do this and practice higher-level thinking skills. Not only are my students better at recognizing the amazing talents of nature around them, but they are also able to make connections between these natural talents and how they can attend to human challenges. As a teacher, it is nice to know the lessons I teach are directly connected to the NGSS and, even more, that my students were actively engaged in every one of the investigations. I highly recommend this curricular unit to any 3rd – 6th grade classroom or specialized teacher!"

Diane Bradford, Lincoln Elementary, Iowa City, IA

"I liked this unit because there were some very cool things and it was interesting. I really like this last thing where you create things. I like doing these more independent things. I also think that it is cool that nature inspired so many things. It was fun and exciting the whole time."

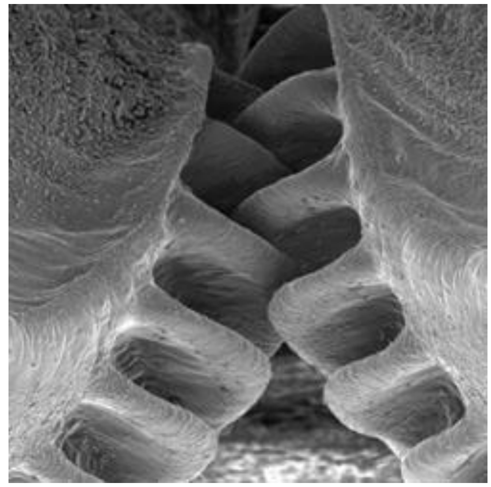
Oscar, 5th grade

"Loved this! Thanks for reminding me of my love of nature and science, and thanks for the awesome connection that technology and nature can come together and create this beautiful outcome."

Principal Jennifer Allen, Orangewood Elementary, Greenfield, CA

^ Color in living things is sometimes created with pigments and dyes, but often instead made using reflective structures that amplify certain color wavelengths, such as in this stunning blue butterfly (*Morpho spp.*). No blue pigment or dye exists in this butterfly at all; the color is produced instead by selective amplification of blue wavelengths of light, using concave structures on its wing scales the exact diameter of blue wavelengths of light. Like a guitar body, these concave structures amplify the vibration our eyes interpret as the color blue. Among its many applications to human technologies, structural color learned from the natural world is now used in advanced electronics to produce vibrant displays which get brighter in sunlight and require little to no battery power. *Butterfly courtesy of Izzy LeCours and Qualcomm watch by the author.*

^ For a creature that spends its life squeezing through dirt, it’s a wonder how earthworms keep themselves so clean. Researchers from China discovered that the movement of earthworms gives their skin an electrical charge. This causes water (a polar molecule) in the surrounding soil to flow towards them. In other words, an earthworm is ingeniously designed to induce the environment to lubricate its journey, keeping earthworms clean and friction-free – effortlessly. This discovery inspired engineers to attempt using small electric currents to keep earth-moving equipment dirt-free. Not only does the method work, it reduces the consumption of fuel and saves time and effort. *Earthworm courtesy of Domagoj Kurmaić. Earthmoving equipment courtesy of Professor Luquan Ren and Dr. Yuying Yan.*



^ The several thousand species of leafhoppers are all known for their ability to jump. Hopper nymphs have an interlocking rotary gear mechanism on their upper legs, which synchronizes thrust in their legs, helping ensure these longjumping insects travel straight forward without spiraling. This ingenious mechanism precedes the invention of cogged wheels by humans (used today in everything from automobiles, airplane engines, and clocks) by about 145 million years. *Scanning electronic microscope image of cog mechanism in planthopper courtesy of Malcolm Burrows and Gregory Sutton.*

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Extraordinary people visualize not what is possible or probable, but rather what is impossible. And by visualizing the impossible, they begin to see it as possible.

Cherie Carter-Scott

I am always doing that which I cannot do, in order that I may learn how to do it.

Pablo Picasso

If we did all the things we are capable of, we would literally astound ourselves.

Thomas A. Edison

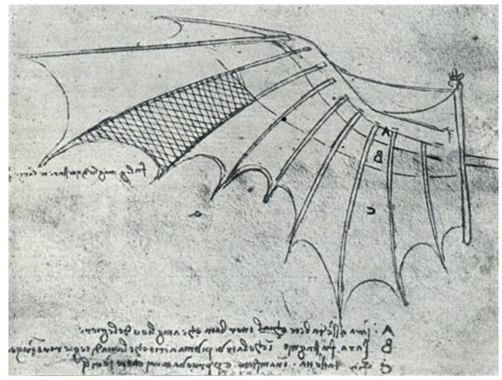
INTRODUCTION




Sometimes it seems like children, Nature, and invention were made for one another. After all, what other combination of things produces so much potential?

We often forget we live in a world brimming with ingenious and astonishingly capable invention. Rigid trees survive hurricane-force winds, glueless geckos scale sheer walls, and hummingbirds zip hundreds of miles on a single, thimble-sized drop of flower nectar. One needn't go far to notice Nature's remarkable talents. House flies undertake maneuvers no jet fighter pilot would attempt, lawn grass can bend thousands of times without breaking, and bananas literally change color to tell you they're ripe. Meanwhile, everything in Nature, from the smallest microbe to the giant redwood forests, is designed in such a way that it works without draining the Earth's resources, polluting the environment, or creating waste. We are surrounded by genius, and we are surrounded by genius that endures.

Individually, the ability to recognize design in the natural world, and understand what it achieves functionally, can result in a greatly enriched lifetime of marvel and enjoyment. Societally, this world of organic genius can stoke humankind's creative abilities to completely reimagine our own technological world. Many of our most well-known engineers and inventors have taken just such a perspective, drawing inspiration from the natural world to make astounding leaps of innovation. Most famous of these inventors perhaps is Leonardo da Vinci, with his bird and bat-inspired flying machine concepts. Of even more consequence are those Nature-inspired engineering ideas embodied in Alexander Graham Bell's invention of the telephone (modelled on the mammalian middle ear), in the Wright brothers' development of the airplane (enabled due to a breakthrough inspired by watching birds), and in Claude Shannon's insights about mimicking patterns of human logic in electronics, the essence of the "logic circuits" that make today's computers run. Without these inspirations from the natural world, these technologies which so profoundly shape our modern world would not exist.



Perhaps the most well-known engineer of all time, Leonardo da Vinci (1452-1519) was a close observer of the natural world who applied what he observed to his creations.

Imagine, for a moment, if phones, airplanes, and computers had never been invented. How different would our human-built world be? If anyone doubts Nature plays an enormously influential role in the character of the modern world, they simply don't know the history of technological innovation.

Today, the tradition of looking to Nature for innovative technological ideas is in its golden era, having grown into a practice regularly used by professional engineers, architects, and designers of all kinds, and referred to as "bio-inspiration", "biomimicry", or "biomimetics".* Nature-inspired approaches to engineering and design are now taught in colleges and universities around the world, including Harvard's Wyss Institute of Biologically Inspired Engineering, the Center for Biologically Inspired Design at George Tech, Caltech's Center for Bioinspired Engineering, Oxford University's Programme on Bio-Inspired Quantum

* Worthwhile TED talks on the subject include https://www.ted.com/talks/janine_benyus_shares_nature_s_designs, and https://www.ted.com/talks/michael_pawlyn_using_nature_s_genius_in_architecture

Technologies, the Imperial College of London's Centre for Bio-Inspired Technology, and many more post-secondary institutions around the world too numerous to list. The point being, innovation inspired by the natural world is how today's engineers-in-training are taught.

The technologies being developed today that Nature has inspired are possibly even more revolutionary than the telephone, airplane, or computer. These include continuing breakthroughs in medicine (gene therapy and immunotherapy are medical procedures inspired by Nature) and artificial intelligence (machine learning and neural networks are bio-inspired ideas). Inspired by trees, there are companies today which produce petroleum-free plastics literally from air (Newlight Technologies, www.newlight.com); companies which produce cement without emitting any greenhouse gases, inspired by the chemical processes used by coral reefs (Calera Corporation, www.calera.com); companies which reduce the weight of redesigned products by mimicking how bones optimize their shape (SolidThinking, www.solidthinking.com); and companies which make Styrofoam substitutes inspired by fungi that break down in your garden, rather than last for thousands of years in landfills (Ecovative, www.ecovativedesign.com). In short, Nature-inspired innovation has provided humankind the aspiration, insight, and ability to make the stuff of modern life out of air, without emitting greenhouse gases, using the most economical amount of material, and which fully recycles itself. If we can continue pursuing technological goals such as these, humankind may very well earn the right to claim it is a sustainable species like the rest of its planet-mates, and the opportunity to live as prosperously on this planet for as long as the rest of Nature does.

A technologically-improved and sustainable human-built world inspired by Nature are possibilities we think the next generation should learn about in school. We began pursuing this goal in 2013, with the development of the middle and high school version of *Engineering Inspired by Nature*. Winner of multiple awards, this curriculum is now being used by hundreds of school teachers around the world, reaching

Engineers and designers now routinely use computer-assisted design (CAD) software inspired by bones, which can remove unneeded material during the design process from objects. This amounts to gigantic material savings, and in things like cars and airplanes, tons of avoided carbon emissions. Images courtesy of Seth Astle, 3D Systems.

thousands of young people every year.[*] We're excited now to offer a version for upper elementary grades. Nature-inspired engineering is a great approach to STEM/STEAM learning because of how it engages young minds and because of how it reflects trends in post-secondary education and professional practice. But even more importantly, since we are surrounded by Nature and technology in one form or another, an engineering education taught from the perspective of what engineers can learn from the living world around us is the basis not just of an excellent engineering education, but an educational experience with the power to transform and enrich children's entire lives, through changing how they value the world and see what's possible in it.

What engineering content can children learn through this approach? Any engineering content is possible to cover through a Nature-oriented approach. These lessons cover topics in material science, structural engineering, and mechanical engineering, as well as physical concepts related to mechanical forces, waves, and fluid dynamics (air and water), and many opportunities for design, testing, data collection, and optimization. The unit provides ample opportunity to meet the requirements of the Next Generation Science Standards for Engineering Design, as well as standards in other subjects (e.g., Life Science, Physical Science, etc). These connections are discussed in detail in the next section, as well as throughout the subsequent lesson plans.

What you *won't* see in the upper elementary version of *Engineering Inspired by Nature* is an exploration of environmental or sustainability topics, which is intentional. Why is that? Just like everything in effective education, information and activities must be sequenced. And children need to fall in love with Nature before they begin to worry about it. While the middle and high school version of *Engineering Inspired by Nature* explores sustainability in great depth, the upper elementary version of the curricula instead focuses on the wonders of Nature and its value in helping people problem-solve and create in effective, ingenious, and novel ways.

The upper elementary grades are a precious period of time in a student's life. The rare combination of innocence, enthusiasm, and interest tends to find its strongest combination during these years. Nature-inspired engineering works extremely well as an approach to engineering education during this time period, for the approach has its own unique combination of qualities that resonate with children in these grade levels, including creativity, imagination, careful observation, inquisitiveness, deductive and analogical reasoning, problem-solving, team work, and much more. As such, Nature-inspired engineering is an obvious choice of approach for engineering education. However, until very recently, materials and training for elementary teachers have been lacking. We hope this unit goes some distance to help correct that situation.

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[*] See https://www.learningwithnature.org/about/our-impact/

How to Use this Material

Students acquire a variety of core competencies during the implementation of the unit, including:

- Students are able to recognize functional design in Nature, and develop greater awareness and appreciation for design excellence in Nature
- Students are able to identify human needs and opportunities that can be addressed through design innovation
- Students are able to use analogical creativity to innovate, using biological models to inspire solutions to design challenges
- Students become familiar with various fundamental engineering concepts, in the areas of material science, structural and mechanical engineering, and aeronautics, including mechanical forces, tension, compression, shear, non-Newtonian fluids, cohesion, adhesion, surface tension, hydrophobicity, material structure, material notches, stress concentration, aerodynamics, etc.
- All of the performance expectations, science and engineering practices, disciplinary core practices, and crosscutting concepts for engineering design in Grades 3-5 are met, with additional connections to other topic areas (such as life science).

This unit has an underlying architecture whose logic is important to understand. Comprising ten lesson plans, the unit is designed to give students an introduction to engineering topics and an introduction to Nature-inspired engineering through hands-on activities, ultimately imparting the cognitive skills for students to be able to undertake Nature-inspired engineering analysis and activities on their own. The unit begins with lesson plans devoted to introducing engineering and more specifically, Nature-inspired engineering. Several lessons in the middle of the unit are devoted to the exploration of various engineering-related topics, with the goal of demonstrating the value of Nature-inspired engineering and giving students practice in doing various aspects of Nature-inspired engineering. Finally, the unit culminates in students applying what they've learned to developing a Nature-inspired design concept themselves.

If necessary, the unit can be shortened by removing one or more of the lessons from the middle of the unit, retaining the first introductory and last culminating design activity. Thus, the unit can be accomplished in anywhere from 2-10 or more class periods, in theory. It is essential, however, that students new to the topic be introduced to engineering inspired Nature, and that their learning culminates in an opportunity to design something inspired by Nature themselves (the first and last lesson). The only way to learn how to think and behave like a Nature-inspired engineer is to do Nature-inspired engineering.

Designed with the NGSS. You will see that each lesson and the unit overall has been shaped fundamentally by the Next Generation Science Standards (although they work just as well for programs not using these standards). Alignments are indicated at the end of every lesson. In addition, a very detailed assessment of the curriculum's alignment with the NGSS using the EQuIP rubric is provided as part of the curriculum's materials, found at www.LearningWithNature.org. The unit aligns deeply with the Engineering and Design Standards for Grades 3-5.[*] Other NGSS standards commonly met include those in Life Science, as well as some others in Physical Science and others. Many connections to the Common Core are pointed out as well. Lesson plans also use the 5E framework (different framework sections, e.g., "engage", "explore", etc.) are indicated by underlining).[**] In addition:

- Lesson narratives and activities are fundamentally driven by making sense of phenomena and designing solutions based on understanding phenomena. Nature-inspired engineers draw upon those biological phenomena that help organisms and ecological systems function, in order to inspire solutions to human challenges and opportunities. Thus, lessons involve making sense of biological phenomena and using this understanding to develop solutions to human problems. The phenomena and design challenges that underpin lessons are clearly spelled out in their introduction.

Bio-inspired engineers pursue an understanding of natural phenomena in order to drive technological innovation. Discoveries about the structure and interatomic forces used in gecko feet for strong-yet-reversible dry adhesion have recently inspired revolutionary human-made materials and applications. © Sam Stier (left). ©Power and Syred (center). Man scaling glass wall courtesy of Eric Eason and Elliot Hawkes, Biomimetic and Dexterous Manipulation Lab, Stanford University (right).

[*] These standards are very similar to the Engineering Design standards for middle school as well, so from that perspective, the curriculum covers the NGSS for these grades too, and would be appropriate for 6th graders at a minimum.

[**] https://bscs.org/bscs-5e-instructional-model

- Lessons are designed to develop student competencies from all three dimensions of the NGSS. These connections are found throughout each lesson, summarized in a table at the end of each lesson, and indicated in the EQuIP rubric.

- Students have opportunities throughout the unit , and at the end of the unit, to demonstrate mastery of NGSS Performance Expectations, especially those for Engineering Design (these also correspond to formative and summative assessment opportunities for teachers: see Appendix 3 and 4).

In order to review the unit, we suggest teachers first read through all of the lesson plans and associated media and training materials. Then, either individually, or as part of professional development or teacher training, we suggest you try out the various activities in each lesson so that you are comfortable with them, before undertaking them with your class.

The materials for these lessons are inexpensive and readily available. A kit version of the curricula also contains the materials needed to implement the unit.The unit can be implemented easily without the kit, simply by gathering the readily available materials yourself, or, you can order the kit by visiting www.LearningWithNature.org.

A few notes on formatting. Teaching instruction is non-italicized. Where you see *italics*, this generally indicates teacher narration, more or less verbatim. However, non-italics are also used where there is more flexibility in terms of the level of information teachers may want to share with students (e.g., to provide more customization to grade level). Where media slides are part of the lesson's materials, you may see small thumbnail images of the slides relevant to that part of the lesson inserted adjacent to the teaching instruction/narration; thumbnails are not inserted where the use of media slides is more optional/flexible.

Lastly, **you are the most important part of this curriculum**. As the teacher, your role in introducing and guiding students through this material is the most important factor in its success. You and your enthusiasm are the most important factors in making this curriculum as good as it can be. Curricula is like a road map or written play; only you can drive it home, only you can create an experience to be remembered.

As part of using this curriculum, we ask that you please share feedback with us, in the form of student and teacher evaluations, so that we can improve this work with your suggestions. We also ask that you share images and video of students engaged in the unit's activities, quotes from students about their experience, and copies of student design concepts that you feel deserve special recognition. This feedback helps us improve the curriculum, keeps us motivated, and helps demonstrate to others the value of this work. For students, knowing their design ideas may be shared more widely can also increase their engagement. We maintain a gallery of student design work on our website (http://www.learningwithnature.org/engineering-curricula/earth-innovators-gallery), and welcome students' submissions.

Let's jump in!

1 INTRODUCING ENGINEERING INSPIRED BY NATURE

Taylor F. Lockwood

The love for all living creatures is the most noble attribute of man.

Charles Darwin

What do students do? Students are introduced to the broad topic of engineering and Nature-inspired engineering through a twist on the marshmallow tower challenge. Students first work in teams to design and build the tallest structure they can out of limited materials. However, in this bio-inspired version of a classroom classic, students' towers are then subjected to earthquake-like forces, and students are challenged to redesign and rebuild their towers to withstand earthquakes by applying ideas from the natural world to the challenge of stability.

What do students learn? Engineering is a major part of our world. Engineers create our world through a process involving observation, learning, teamwork, design, prototyping, testing, and optimizing. Engineers often look to Nature for innovative ideas for ways to solve problems and greet opportunities. By learning to recognize the natural world's many capabilities, and applying these insights to the development of our own technologies, we can create amazing things and a better human-built world.

Pedagogical approach: Students begin developing their own concept of what engineering is by having an immediate hands-on experience addressing a design challenge and then reflecting on the process. Students then begin learning what Nature-inspired engineering is by making sense of phenomena in the living world, specifically biological approaches to making tall and stable structures, and applying design ideas generated from understanding these phenomena to the design and testing of their own earthquake-proof towers.

Grades covered. This lesson plan is designed for Grades 3 through 5/6.

Connection to standards. This is an overview of connection points to the NGSS for this lesson; a detailed explanation of these connections is provided at the end of the lesson. All of the Engineering Design standards (in addition to other standards) are covered over the course of the unit.

- 3-5 Engineering Design
- 4-LS1 From Molecules to Organisms: Structures and Processes
- 4-ESS3 Earth and Human Activity

What you need.

- 40 pieces of dry spaghetti for every group of students (~4 students per group)[*]
- 2 meters of masking tape for every group of students
- 2 meters of string for every group of students

[*] This is enough for each group to build two towers. More spaghetti, masking tape, string, and marshmallows may be needed for additional iterations, though materials can also be reused.

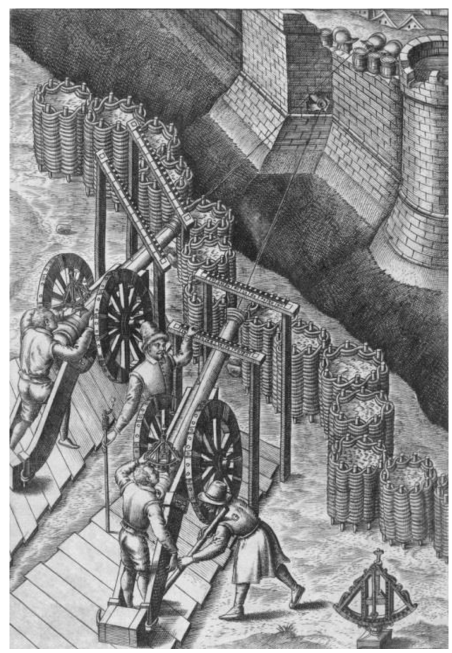
- 1 piece of flat cardboard for every group of students, about .1 square meters (~1 square foot)
- Masking tape
- A way to make a fast, regular, audible beat (free, online metronomes work well, e.g., https://www.google.com/search?q=metronome)
- 1 piece of clear, PETE plastic (#1) per student group (~ 1.5 x 6.6 cm)
- Polarized glasses or polarized plastic film
- Polarized backgrounds (e.g., computer or cell phone screens, or polarized film)
- 1 balloon (optional)
- 1 sewing needle (optional)
- Media materials (provided)
- 1 regular marshmallow for every group of 4 students (not mini, not jumbo-sized; a regular-sized marshmallow is about 2.5 centimeters or 1 inch diameter)
- Bag of marshmallows, optional (1 for each student, to eat)
- Music (optional)
- A writing journal for each student

Time required. Two class periods of approximately 40-50 minutes each.

Background for teachers.

This lesson does two very key things to kick off the unit:

1) It introduces the subject of engineering to students, and
2) It introduces the practice of engineering inspired by Nature to students.



As far as we know, "Engineering" was a term first used in 1325 to refer to mechanical weaponry. Today it is used much more broadly. Engineering is a process in which people design, make, and optimize things to improve the quality of life.

What is engineering? We mean "engineering" in its broadest sense. The first known use of the term in 1325 referred to people who made mechanical weaponry, but today it applies to people who craft virtually everything, from molecules to megacities. Its Latin root, *ingeniare*, is a verb meaning "to contrive, to devise." For our purposes, engineering is any activity in which people design, make, and optimize things to improve the quality of life.[*]

You don't need to go very far to see why engineering is important. Just take a moment to look at the various things that surround you right now: for me, this includes the computer I'm typing on (and the software program it's using), a desk, a microscope, a box of Kleenex, a pair of polarized sunglasses, some Legos, a tin of cinnamon-flavored mints from England (empty, sadly), a ceramic mug of steaming coffee, and dozens of other items. What is the one thing that all of these objects have in common? All of these objects are the fruits of human engineering activity, transforming materials and information through design, making, and optimizing into new objects with new possibilities.

People live in an increasingly human-engineered world, from the cars we drive, to the food we eat, to the cities we live in. You can similarly make your students aware of the importance and pervasiveness of engineering in our world, simply by having them notice the school building, classroom items, their clothing, backpacks, the roads, cars, and houses all around the school – all of these products of engineering, made by engineers who design and fabricate the many, many human-made things that surround us and influence our lives in countless ways.

One objective of this first lesson is to help students better understand what it is engineers do, a wide variety of activities that includes thinking about technology, observing what could use improvement, dreaming up what doesn't yet exist but should, testing the performance of prototypes, innovating, inventing, and on it goes. You can only tell children so much, however, so learning what engineers do is something they'll come to better understand over the span of the unit, not only during this single lesson. This lesson will also help students begin to understand what engineering is experientially, by having students do a hands-on engineering-type activity.

Another objective of this first lesson is to make students aware that engineers often draw inspiration from the natural world around us for ideas. Nature is already full of ingenious and effective solutions to an immense range of challenges, so many engineers today derive their ideas by looking at how Nature works. In this unit, students will learn how engineers do this, and learn to be able to do it themselves. This objective is addressed briefly in this lesson through providing examples of Nature-inspired engineering and an activity, but it is also a concept the unit is designed to deepen in students over time.

Finally, the last objective of the lesson is to begin helping students develop the observational and critical thinking skills of a Nature-inspired engineer. Nature-inspired engineers, like all

[*] The NGSS includes engineering standards, but they are referred to as "Engineering Design" standards to emphasize the role of design in the engineering process.

engineers, notice needs and opportunities for improving how our world works, but they also notice what Life is good at doing, and how to become inspired by Nature's talents to innovate. This vital objective is pursued intentionally and strategically through the various activities of the entire unit, as well as outside of class.

Preparation.

- Ready your materials.
- Test out your shake table (see below) to find a good set of parameters (distance and beats per minute) for testing marshmallow towers.
- Find music selections (optional).
- Queue up the videos (see below).

To Do With Students.

1. Explain to your students that for this unit, you'll be exploring the world of engineering.[*] Engage your students with a discussion: what do your students think of when they hear the word "engineering"? What is engineering? What do engineers do? Make a list on the board of the students' ideas. Since "engineering" can be a broad term covering many different types of jobs and activities (including the work of architects and designers), it's good if the list is long. Here are a few key ideas to make sure to get across:
    - Engineers envision, design, make, and optimize (i.e., improve through testing) what the world wants and needs.
    - Engineers observe and learn about the world to identify things that could work better.
    - Engineers use their imaginations, creativity, and other tools to dream up what can be made and how to make it.

2. Let's begin moving from the abstract and theoretical to the tangible: ask your students to look around them and find things that engineers have made. Pencils, pens, paper, chairs, desks, books, the physical school, the landscaping around the school, cars, houses, the clothes the kids are wearing – all of these items are the result of the work of engineers. Let students add to a growing list of things engineers design and make. How do these things make the world a better place? (*What if we didn't have houses, or cars,*

[*] To provide a benchmark for comparison, this could be a good time to ask students to write down on a piece of paper how engineers get their ideas, or other measures of interest, questions you can repeat at the end of the lesson and unit. A sample pre-test is provided in the appendices.

etc.?). The point is to help students recognize engineering as a pervasive and valuable part of our world.

To show students some of the various things engineers make, see the provided media materials (slides 1-6).[**]

3. To further <u>explore</u> what engineers do, let students know that today, they are going to be engineers themselves, working in teams to make a tower out of spaghetti.[*] (Dry spaghetti!)

   Form the students into teams of about four and explain the rules for the challenge:[**]

   > Each team will build a tower with the materials provided. The goal or criteria for a successful tower is one that (a) is complete at the end of the allotted time, (b) is as tall as possible, (c) stands on a piece of cardboard by itself using only the materials provided, and (d) has the marshmallow at the very top.
   >
   > Every team will be operating with the same constraints in terms of materials and time. Each team will get 20 dry pieces of spaghetti, one meter of masking tape, one meter of string, one regular-sized marshmallow, and 18 minutes to build their tower. At the end of the time, each tower which meets the criteria for success (above) will be measured to see which one is the tallest.

   Hand out the material to each group, and begin the timer.[***] After the time is up, measure the towers to determine the tallest tower.


A simple experiential way to begin learning what engineering is, and to set up an introduction to Nature-inspired engineering. Images courtesy of IDEO (left) and Wesley Fryer (right).

[**] All media materials can be found at www.LearningWithNature.org

[*] Known as the "marshmallow challenge", this activity is done with school children and adults alike, usually as a way of exploring teamwork. It has a long history which you can explore online. If students have already done this activity, don't worry: this version is very different.

[**] Remember to compose groups and teams leveraging diversity, to provide optimal opportunities for students of different backgrounds and abilities.

[***] An opportunity to play some motivating music in the background.

4. Facilitate a discussion to debrief about the marshmallow tower experience. Give students a chance to explain what it is engineers do, based on what they just experienced; what's ideal about this approach to introducing engineering is that students can now give responses based on their own personal experience. Ask students to try and describe what they did in building their tower as a series of steps. Consider drawing these steps on the board, and note concepts you feel are important to the engineering process, such as: defining a challenge and criteria for success, recognizing constraints (such as materials and time), working as a team, etc.

   So it sounds like, from what you're describing, that engineers do a variety of different mental and physical activities. And it sounds like these different things that engineers do happen in a certain order, more or less. So we could say that engineering is a process.

   And it sounds like, in this process, engineers use many different parts of their minds, such as their imaginations, observational skills, and analytical abilities. You can refer here back to the list you made with students earlier. *To begin with, engineers think about what needs to be made. In this case, you were given the challenge. But other times engineers design and invent things no one told them to make, right? Sometimes engineers make things they come up with – they invent things. Engineers are also learners: they learn by observing, working together, and testing things, to figure out how things work, and how they might make them work better.*

   Just like you all just did, engineers come up with ideas for how to address challenges and opportunities, develop designs, build models or prototypes of their ideas, test their solutions, and communicate about their ideas with others. These are the many things engineers do! And as part of this engineering unit, you all will get to do more of these things too.

5. Test students' marshmallow towers now for their stability. *For instance*, you can begin, *the towers you just built were supposed to be as tall as possible. But very often engineers have to meet more than just one goal in their designs. Demand for taller and taller skyscrapers is increasing, for example, and taller buildings often have to also be more stable. What would happen, for example, if the towers you just built were subjected to high winds, or an earthquake.* [*] *Do you think your towers are stable against earthquakes? How might we test to see if they are?*

[*] If earthquakes or high winds occur in your region, or have been in the news for other regions, you can refer to these here, in order to make your point more relevant and authentic for your students.

This is a great opportunity to get students thinking about what makes an effective as well as fair test. See what they come up with, and discuss the fairness of their ideas.

A very simple shake table requires only masking tape and a metronome. Image courtesy of Dr. Doug Williams.

6. Describe the testing protocol to students. In order to test the towers for stability, each tower will be shaken over a standard distance (e.g., 6 centimeters, or about 2.5 inches). Place two pieces of masking tape parallel to each other, a set distance apart. The towers will be shaken at a standard speed (e.g., 150 beats per minute), which you can measure using a metronome (online metronomes work well). The teacher can be the shaker, or you can assign it to students. Note, one "shake" means the cardboard base of each tower moves from one piece of masking tape to the other, and back (one complete cycle), with each beat (if you make each "shake" be just the movement from one piece of masking tape to the other, and not back again, the beats per minute have to be doubled, the sound of which can be difficult to follow with hand movements). Test each tower for a set amount of time (e.g., 10 seconds). For the lesson, it's beneficial if most, if not all, of the towers experience some damage or collapse. Students will be challenged to rebuild them in a moment. *All right, well we're certainly not going to give up! Let's rebuild our towers, and this time, design them to be both tall and stable. Where might an engineer go to get ideas for how to make a tower more stable?*

7. Further extend students' ideas about what engineers do, by introducing the idea of engineering inspired by Nature. Invite your students to look at their own hands: *Take a moment and look at your own hands… We've talked about how engineers invent things, but who invented those? Did engineers invent your hands? No! Who then? Nature invented our hands, right. Did you ever think that Nature could invent things? Nature invents a lot of things! Trees, ants, birds, snakes, people – Nature has invented thousands and thousands of things.* (Gesture out the window). *Everything out there has been invented by the processes of Nature, which constantly makes and optimizes new things. And the things Nature makes seem to work very well. Think of all the different things you can do with your hands!* To emphasize the

point, you can have students jointly develop a short list of different functional things hands can do (e.g., grab, scratch, point, signal, feel, etc.).

Let's say engineers wanted to invent a robot that is good at picking things up, do you think they might look at how hands work? Yes! Why wouldn't they? Nature has already made something that is very, very good at picking stuff up, right? Hands, invented by Nature, could help engineers envision how a robotic hand might be designed.

8. *So, does anyone have ideas about where engineers can go to get ideas for how to build towers that are both tall and stable?* Give students a chance to indicate that Nature may have ideas about this. Reinforce the point: *that's right! After all, humans are not the only species to make tall structures* (see slide #8). *Next, we'll explore some ways Nature stabilizes structures, and see if this gives us some ideas of how to design our towers to be both tall and earthquake resistant.*

This is a good place in which to break the lesson into two parts, if necessary (it's also a great time to hand out marshmallows to reward everyone for their effort so far!).

9. *Let's look at some ways that Nature stabilizes vertical structures*. In this section, you'll explore various strategies with students used in the natural world to stabilize structures. These strategies present phenomena which can drive curiosity and learning through the next section. Understanding of the phenomena explored will inform students' design solutions in the next iteration of their earthquake-resistant towers.

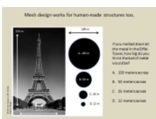
    - *Stabilizing with struts*

      Bone is a good example of the use of mesh design. Bone isn't solid, it uses a meshwork of struts with lots of interpenetrating space. Struts are structural members that often direct and resist compressive (pushing) forces. In bone, these members are called trabacula (plural: trabaculae). Why are bones designed this way? It seems like a meshwork structure would be weaker than a solid structure. However, a meshwork structure allows bones to be bigger yet just as strong as a solid structure, without having to be heavier or use more material.

      Ask students to look carefully at the physical samples or media slides (#9-12) of bone (if you have a physical example of bone showing trabeculae that you can share, this is helpful, though images are provided which will also work). What do students notice about bone that is a little surprising? Bone isn't solid! It's made of a meshwork of material, encompassing a lot of space. Solicit students ideas for why bone might be designed this way. To help students think about this question, you can prompt their inquiry with additional questions like:

- *If bone were solid instead of a mesh, what would be different about it?* (It would be heavier). *If bones were heavier, would that be a problem? How would heavier bones impact, say, a cheetah running after a gazelle? Or a gazelle running from a cheetah?* (Solid bones would make movement more difficult).

- If our bones were solid instead of containing space, how would this impact how much food we need to eat, and how much time and energy it would take our bodies to make bones? Is it difficult for our bodies to make bones? Where does the material of bones come from? (calcium comes from dairy, leafy green vegetables, etc.)./Solid bones would take more nutrients, time, and energy to make.



- If bones were solid instead of containing lots of space, do you think they could be smaller, but just as strong?/Yes./How would this impact the size of animals?/They could be smaller./Would a smaller cheetah be just as good at hunting gazelle as a bigger cheetah? Would a smaller gazelle be just as good at running from a cheetah as a bigger gazelle?/By using a mesh design, bone can be bigger in size yet light, and just as strong as solid bone.

- *Moving structural support to the outside*

Stems, like bones, also have the job of holding things up. What do you notice that these three different plant stems have in common? Give students time to formulate their answers. *Have you ever wondered, why are things like dandelion stems hollow? If stems have the job of holding a plant up, and supporting it against the wind, why do you think all of them are hollow in the middle?*

You can have students model how bending forces move through a stem by using rectangular pieces of clear #1 PETE plastic (polyethylene terephthalate) and polarizing filters. Have students hold the ends of their piece of 1.5 x 9.5 cm plastic horizontally, and apply a twisting (torsion) force to the plastic while viewing the plastic between two polarizing filters (e.g., polarizing sunglasses and either a white computer screen, cell phone screen, or polarizing filter taped to a window). Explain that the lines and colors they see in the plastic are a direct consequence of twisting: these patterns show where force concentrates, and where it doesn't, when the plastic is twisted. What do the students notice?

When a beam, like a plant stem, is bent or twisted, force concentrates at the beam's edges.

Does this help explain the structure of the plant stems in the previous slide? That is, does this help us understand where the material is, and where it isn't, in these plant stems? Why?

Ask a willing student to help you demonstrate why plant stems concentrate their material at their edges. Have a student stand next to you with their feet together. *When you're standing, what's one of the first things you do when something shakes you?* Hold the student's shoulders and move them back and forth gently but firmly, until they spread their feet apart. *That's right, you spread your feet apart. Your body knows what to do to resist shaking. So do plants.*

Most of the bending forces impacting a structure occur at the outer perimeter of a structure; placing material at the edge of a structure more effectively resists these forces than material in the center of a structure. This is also the same reason an I-beam is shaped like an 'I' instead of just being shaped like a square: the 'I' shape concentrates more of the beam's material at its edges, where the bending forces are.

Here are several additional strategies Nature uses for stabilizing structures (see slides #20-25):

- *Stabilizing with buttresses*
  Some termite mounds and trees demonstrate buttressed structures. Why do buttresses help stabilize a structure? Buttresses help stiffen a structure and prevent too much side-to-side motion. Some large churches also exemplify buttressed structures.

- *Broadening the base*
  Why would broadening the bottom of a structure help stabilize it? Broadening the base of a structure helps spread the force of lateral motion across a larger area and the risk of toppling if any part of the base breaks.

- *Tightening with tethers*
  Tethers stiffen a structure using tension, pulling it equally in opposite directions and down to the ground.

- *Dampening shake*
  A structure with components that move opposite to the primary motion counterbalances the structure, and will tend to reduce the overall force with which a structure shakes back and forth.

- *Strengthening areas of stress or failure*
  Many things in Nature strengthen or repair themselves where stress occurs. Our bones are a good example of Nature repairing where stress or a fracture has occurred. Trees also do this, adding woody material to stressed areas in order to strengthen them.

10. Have students work in the same teams as before, and with a fresh set of materials and 18 minutes of time, redesign and rebuild the tallest towers they can that are also stable. First, have students examine the first iteration of their towers and try to describe and identify where and why they may have failed. Then, have students redesign and present their rebuilt towers to the class while explaining what they learned from the failure of their first tower, which strategies they borrowed from Nature, why they chose these, and how they applied them to their design to improve their tower.[*] An option is to have students try to guess which towers will withstand shaking and explain their rationale for choosing the tower(s) they do.

11. Retest each tower with the earthquake simulation, and measure the height of each tower afterward. You can record the results for the students to see like this:

Tower designed by:	**Strategies applied**	**Height after quake**
Jeremy, Blaine, Felicia	Buttresses, counterweight	20 cm

You can add more rounds of redesigning and testing depending on time and interest.

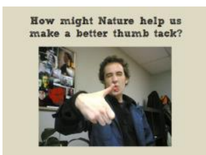
12. Ask students to reflect on what they learned from the tests of their own towers and those of their classmates. Encourage students to provide feedback to their peers during the discussion. For example:

- Which towers were tallest after the shake table test? Why? Are there similarities in how the tallest towers were designed?
- Ask students of the tallest towers how they thought about the design of their towers.
- How can Nature help engineers innovate/invent/optimize?

[*] A good formative assessment opportunity for evaluating if students are using analogical reasoning and applying biological ideas to technological applications.

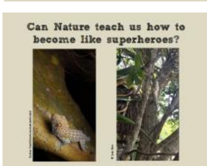
- Discuss as a class about the value of testing and redesigning. How is this similar/different to the tests that scientists perform?[**]
- What makes this a fair test? (By testing each tower using the same shaking conditions, each tower is "fairly" tested relative to the others).
- Point out that when designing something, there are often both criteria that must be met, and constraints on what you make. What were the criteria that had to be met by the towers? (height, stability) What constraints were there on the towers? (materials, time)

13. Now that your students have experienced using Nature-inspired approaches to solving challenges themselves, show them some additional ways other people have used inspired engineering to solve problems and drive innovation. There are hundreds of examples to choose from, and it's great to assemble your own favorites (see resource section below for research tips). *Has this ever happened to you when you were reaching for a thumb tack? Well, it happened to a designer named Toshi Fukaya. Toshi wanted to create a new design for a thumb tack that wouldn't accidentally poke you. One day, watching his cat playing, Toshi started paying attention to his cat's claws. Cat claws are retractable. They aren't out, exposed all the time. A cat's claws only come out when they want to use them. Otherwise, Toshi noticed, his cat's claws were safely enclosed, covered inside his cat's soft, furry paws.*

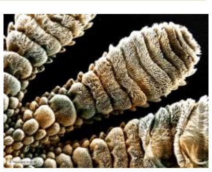


Toshi got an idea from this. He redesigned the thumb tack to be enclosed by a flexible capsule. Press it into the wall, and the capsule compressed. Pull it back out of the wall, and the capsule encircled the sharp metal pin again. It was like his cat's claws, a retractable thumb tack. That was a thumb tack that wouldn't accidentally poke you!

Here's another example of engineering inspired by Nature. This is a gecko. You may already know that geckos can climb almost any surface. They don't use glue or suction cups.



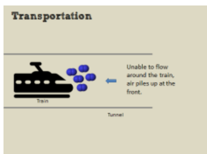
Instead, their feet have millions and millions of microscopic hairs on them, that are so small, (say this slowly!) *the atoms of the hairs can combine temporarily with the atoms of whatever surface they're walking on.*

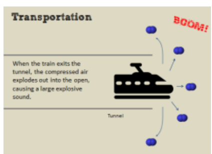


[**] Science and engineering share many similarities, especially in that both use tests to draw conclusions. In general, we could say that scientists test existing phenomena to try to understand them better, while engineers test human-made designs to try to optimize their performance.

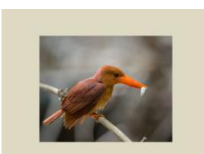
Engineers are now able to mimic or copy this idea in human-made materials, so that for the first time, people can use special materials inspired by geckos to climb any surface, even the side of a glass building, just like Spiderman.

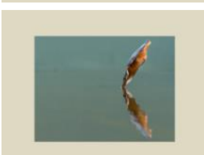
We have time for one last example for today[*]*. This train is called the Bullet Train because it's one of the fastest trains in the world. But it had a problem. When the Bullet Train traveled through tunnels, air inside the tunnel didn't flow around the train. Instead, it got stuck at the front of the train, piling up* (blow some air into balloon), *and piling up* (blow some more air into balloon), *until it got pushed out the other side of the tunnel. Now, when all that air suddenly exited the tunnel, there was a big* (pop balloon) *POP sound!*



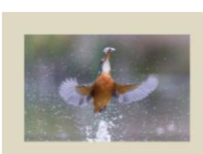


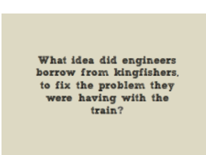
When people complained about the noise, the engineers had to find a solution. One idea was to widen the tunnels, but that would be very expensive! Instead, the engineers found a much more effective and less expensive solution… which mimicked a bird! Anyone know what kind of bird this is? (Kingfisher). *And does anyone know what this bird does to eat? There's a hint in its mouth.* (It dives into water to catch fish).





Do you think you could catch a fish by plunging your hand into the water and trying to grab it? (It would be hard!). *Why not?* (Even if a fish doesn't see your hand, it can feel the movement of water made by your hand as your hand enters the water. The disturbance of your hand creates waves inside the water that the fish feels. Then it quickly flees). *So how can this kingfisher catch fish?* (A great video to show at this point is here, of kingfisher getting a fish: https://www.youtube.com/watch?v=MQVEdXN_Mnk). *The answer is that kingfishers are designed such that they can enter water very smoothly, without creating a splash. See? No splash as it's entering the water. So the fish doesn't even know the bird is coming until it is too late* (play the video clip again).



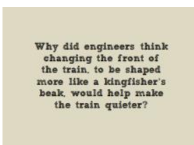


Do you know what idea the engineers came up with to fix the problem they were having with the train, that's similar to the way the kingfisher dives in water without making a splash? (See if any students can figure it out). *That's right, they changed the shape of the train's front end to be more like a kingfisher's beak.*

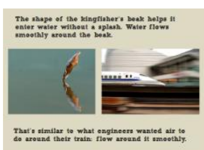
[*] If you have time to share more examples of Nature-inspired engineering, you can find lots of other examples online by searching terms like "bio-inspired", "biomimetic", and "biomimicry".

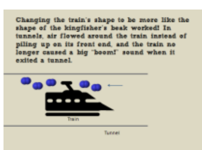
What the engineers did is to make models of trains with different shapes, and propel them through models of tunnels, and measure the noise that resulted. And what they found is that, as the shape of the train became more and more like the shape of a kingfisher's beak, the train got quieter and quieter. So the engineers changed the front of the train from the original Bullet Train shape to a shape that happened to be more like the kingfisher's beak, and the result was that the train traveled much more quietly and needed less energy to run than before.

14. In order to help <u>evaluate</u> what the students have learned, their ability to reason analogically, and articulate their thoughts, have them pull out a piece of paper, put their names on it, and answer this question to hand in:



WHY did the engineers think changing the shape of the train's front to be more like the kingfisher's beak might help the train become quieter?





To assess students' answers, look for an understanding of the analogy between the kingfisher entering water smoothly, without creating a splash, and the need for air to flow more smoothly around the train.[*] After students have handed these in, show the slide and discuss as a class. Like the kingfisher's beak, engineers needed fluid (in this case air, instead of water) to flow smoothly around their train. The shape of the kingfisher's beak provides us with ideas of how to do this.

Ideas are at the heart of engineering. Every human-made thing we can see around us began as an idea in someone's mind. Oftentimes, we first imagine the world we want to create, and then we set out to create it. Just like you may have imagined the tower you wanted to build before setting out to build it. Engineers often look to Nature for their ideas, because Nature is good at doing so many things, in ways we haven't thought of. Nature helps us imagine new possibilities.

15. Have students take out their journals. At the top of one page, have them write the title of the journal: "Challenges and Opportunities: What's Worth Inventing?". Then have them skip several pages, and write at the top of another page: "Nature's Talents: What's Nature Good At?".

[*] See 3D-aligned Rubric and Response Appendix.

End the lesson by summing things up this way: *Nature-inspired engineers have a certain way of thinking and seeing the world around them. Like all engineers, they notice challenges and opportunities to improve things, to make our human-built world better, such as the designer who wondered how to make thumb tacks safer, or the engineer challenged to make the Bullet Train quieter. Every day, you're going to write down in your "Challenges and Opportunities" journal any opportunity you see to make the world a little better, to fix something, or to invent something completely new.** *That way, when you start to invent your own things later in the unit, you'll have a good list started of things worth doing.*

The other thing Nature-inspired engineers practice is noticing what Life is good at doing. Like the engineers who became impressed by how geckos can walk up walls, or how a kingfisher can dive smoothly into water. Every day, you're also going to write down in your "Nature's Talents" journal anything you notice about the living world that impresses you, anything that something in Nature seems good at doing. That way, when you start to invent your own things later in the unit, you'll have a good list started to inspire your engineering ideas and solutions.

By next class, you should have X *items in both journals.* (The number is left to you to determine, but 1-3 seems like a good start.)

At the beginning of subsequent lessons in the unit, have students share with the class items from their journal. Also, at the end of subsequent lessons in the unit, remind students to add more observations to their journals. This will keep students observing and thinking on a daily basis, in between classes, help create greater cohesiveness to the unit, and provide students an important resource for when they create their own designs at the end of the unit.

Extensions/Expansions and other fun related things to try.

With more time, you can add more examples of Nature-inspired engineering. There are hundreds to choose from, found easily online (key search terms include "bio-inspired", "biomimetics", and "biomimicry"). Naturally, you'll want to choose examples that students can relate to and will find inspiring. For 5th graders, see Appendix 1. For motivated students, a good homework assignment is to ask students to research a Nature-inspired innovation that appeals to them and provide a short written and/or spoken report about it, e.g., to share with the class.

[*] This supports the disciplinary core idea of Defining and Delimiting Engineering Problems (ETS1.A), and is developed further in subsequent lessons in the unit.

Detailed connections to the NGSS.

3-5.Engineering Design	
Performance expectations	
3-5-ETS1-1	Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. *Students are introduced to the idea of defining problems and criteria and constraints by being given the straight-forward design challenge of making a tall tower, then making a tall tower that can withstand a simulated earthquake (i.e., criteria for success) with constraints on both materials and time.*
3-5-ETS1-2	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. *As a class, students generate multiple versions and iterations of tower design solutions and compare them against criteria for success (height and stability) within material and time constraints.*
3-5-ETS1-3	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved. *Students carry out tests where variables are controlled (e.g., shaking frequency) and design weaknesses are considered as well as their modification to better meet criteria for success.*
Three Dimensions	
Science and Engineering Practices	**Asking Questions and Defining Problems.** Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost. *Students come to understand a well-defined and simple design challenge (tallest, stable structure) and its solution through the development of a model tower within certain criteria and constraints.*
Science and Engineering Practices	**Planning and Carrying Out Investigations.** Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered. *Students work in teams to plan and test structures to produce basic data (height, stable/not stable) using controlled testing procedures.*
Science and Engineering Practices	**Constructing Explanations and Designing Solutions.** Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem. *Students create at least two design iterations and as a class many design solutions to a design challenge defined by certain criteria and constraints.*
Disciplinary Core Ideas	**ETS1.A: Defining and Delimiting Engineering Problems.** Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. *Different design solutions for towers are compared based on their success in meeting established criteria within defined constraints.*
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions.** At whatever stage, communicating with peers about proposed solutions is an

	important part of the design process, and shared ideas can lead to improved designs. *Students work in team at several points to decide their tower designs.*
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions.** Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. *Students use tests designed to identify weaknesses in their towers' stability.*
Disciplinary Core Ideas	**ETS1.C: Optimizing the Design Solution.** Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. *Many different tower design solutions, all equally constrained, are tested to see which successfully meet the design criteria.*
Crosscutting Concepts	**Influence of Science, Engineering, and Technology on Society and the Natural World.** People's needs and wants change over time, as do their demands for new and improved technologies. *Students become aware of increasing demand for taller buildings as society grows and changes, creating new opportunities and challenges for engineers (e.g., p. 14).*
Crosscutting Concepts	**Influence of Science, Engineering, and Technology on Society and the Natural World.** Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. *Many examples are shared with students that illustrate the work of engineers to innovate and improve human technologies.*

4-LS1 From Molecules to Organisms: Structures and Processes	
Performance expectations	
4-LS1-1	Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction. *Students are given evidence needed to form an argument that various structures help organisms function better, such as the beak of a kingfisher helping it enter the water smoothly to catch fish.*
Three Dimensions	
Science and Engineering Practices	Engaging in argument from evidence. Construct an argument with evidence, data, and/or a model. *Students are given the opportunity to use photographic and other evidence in arguing that water flows smoothly around a kingfisher's beak. (4-LS1-1)*
Disciplinary Core Ideas	LS1.A. Structure and Function. Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. *Students learn that the structure of many elements in Nature (e.g., geckos' feet, kingfishers' beaks, bone, plant stems, etc.) enable them to achieve a variety of functions (e.g., walk on virtually any surface, catch fish, support animals, resist wind, etc.). (4-LS1-1)*

Opportunities also exist to connect with these other performance expectations by asking students to specifically consider these contexts when they list challenges in their "Challenge Opportunities" journals:

3-ESS3 Earth and Human Activity. 3-ESS3-1. Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard. *The challenge can be framed as building to resist wind as well as earthquakes.*

4-ESS3 Earth and Human Activity. 4-ESS3-2. Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans. *Students develop tower models to withstand earthquakes.*

Did you know?

Marshmallows originated from the roots of marshmallow plants (*Althaea officinalis*), used first for medicinal purposes, and then made into a dessert by the ancient Egyptians. In the 1800s, French cooks developed the basic recipe we're familiar with today.

Marshmallow plant (*Althaea officinalis*)

Connections to other subjects

Have students draw something you talked about in class, or something they find that Nature is good at doing. How does it work? Communicate how you think it works through illustration.[*]

Connectivity to the rest of the unit

For the rest of the unit, students will be learning engineering concepts through a Nature-based approach.

There may be opportunities to share other examples of engineering inspired by Nature throughout the unit, for example, at the start of class. For example, see the Engineering Inspired by Trees in the appendices, particularly for 5th grade students.

Also, at the beginning of subsequent lessons, you can ask students to share their "Challenges and Opportunities" and "Nature's Talents" journals with you and/or the rest of the class. The more routine and regular a practice you can make this, the more you can help develop students' observational and cognitive abilities as Nature-inspired engineers.

Credits

Marshmallow plant courtesy of gailhampshire

[*] The final project of the unit will require students illustrate their engineering ideas and the biological mechanisms that inspired them, so incorporating illustration early and often will serve students well.

Kingfisher drawing courtesy of Satomi Nakatsu, eldest daughter of Eiji Nakatsu, former Chief Engineer of the Bullet Train

References

- Draw an engineer test:

Knight, M. and Cunningham, C., 2004, June. Draw an engineer test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. In *ASEE Annual Conference and Exposition* (Vol. 2004). Available online at https://pdfs.semanticscholar.org/8292/8f673c2759f953472e5cc69ce463e9d32aa5.pdf

- Gecko-inspired adhesion:

Hawkes, E.W., Eason, E.V., Christensen, D.L. and Cutkosky, M.R., 2014. Human climbing with efficiently scaled gecko-inspired dry adhesives. Available online at: https://pdfs.semanticscholar.org/0ba0/8a6c2dd9f80e7b078164824dd88103dca196.pdf

- Kingfishers and the Bullet Train:

https://issuu.com/eggermont/docs/zq_issue_02r_final/10

Other quick engineering activities:

- http://training.byu.edu/teamBuilding.php
- https://guideinc.org/2014/08/25/team-building-activity-balloon-tower/
- https://www.reddit.com/r/ScienceTeachers/comments/1jvu15/engineering_design_challenges_similar_to_the/

Satomi Nakatsu