Washington and Lee University
ENGN/BIOL 267: Bioengineering and Bioinspired Design
J. Erickson, Winter 2020
Updated: 23 Mar 2020 due to COVID-19

Look deep into nature, and then you will understand everything better. -A. Einstein

Human ingenuity may make various inventions but it will never devise any inventions more beautiful, nor more simple, nor more to the purpose than Nature does. - Leonardo DaVinci

Course Meeting Info

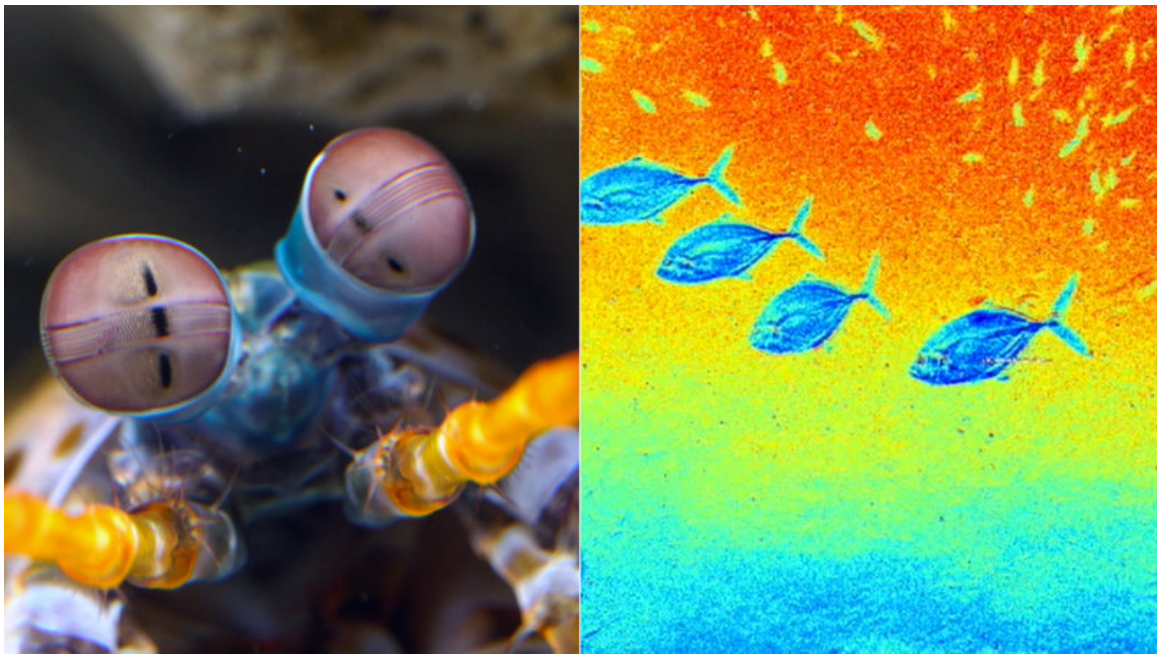
When: TR 9.45–11.15 am
Where: SciAddn 102 (regular class meeting spot) We will also make use of the IQ center Computer Visualization Lab and Physical-Mechanical rapid prototyping facilities.

Instructor Info

Office Hours:	MTW 1.30 - 3pm
	and by appointment (walk-ins welcome!)
Where to find me:	Howe 221 or Howe 222
Phone:	458.8293 or 458.8889
Email:	ericksonj@wlu.edu
Web Page:	`https://erickson.academic.wlu.edu/teaching/bioE_w2020.html`

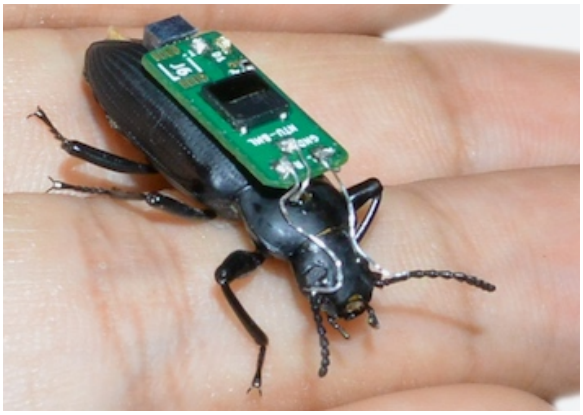
Course Objectives

- Integrate and apply first principles of physics, engineering, and biology/physiology to explain animal amazing behavior/mechanisms.
- Understand the variety of methods and instrumentation used to perform experiments by which these amazing animal properties/behaviors are studied.
- Apply principles employed in biological systems to investigate and create novel devices and solutions to current engineering problems.
- Understand the challenges inherent with attempting to replicate/reverse-engineer biological systems, the promise and peril thereof.



(a) mantis shrimp optics sense polarized light

(b) *A. aurita* and bioinspired jellyfish robot patrolling coral reef



(c) small, agile insect biobot

Figure 1: Some examples of biological inspiration. Image credits: (a) [1], (b) [2] and Getty Images/Oleg Kovtun, (c) [3].

Course Overview

Animals are endowed with some truly amazing capabilities. They come standard with exquisite parts and abilities that far surpass the technology we humans currently have at hand. For example, consider the following:

- The mantis shrimp has amazing eyes that allow it to sense 12 difference wavelengths and polarized light more densely packed and more power efficient than the most state of the art cameras thus helping us develop new and more powerful optical devices!
- A species of spider has the most sensitive vibration sensors on earth, many and has inspired a brand new type of accelerometer that is 2000× more efficient than previous human designs.
- Jellyfish swim and patrol the ocean without disturbing the marine environment and they don't get caught in seaweed (your typical rotary propeller can't do that)
- A beetle hybrid robot can deftly maneuver over rought terrain navigate the tiniest of spaces all using a battery pack (see if your fully human-built robot can do that!).

So, humans have much to learn from looking deeply into Nature. Bioinspired design is about distilling the essence of amazing animal behavior down to first principles of physiology and physics, then integrating what we learned into human engineered systems. We will explore and investigate the physical mechanisms and engineering principles behind the astonishing mechanisms and abilities of animals with topics such as: propulsion kinematics; bioinspired optical devices and materials; and neural-electric control of hybrid insect robots. We'll also explore how these animals are inspiring a new generation of technology. Throughout, emphasis will be placed on study of methods and instrumentation used to perform experiments, by which these amazing animal properties are investigated and understood. During the first 4-6 weeks of the course will investigate 3-4 bioinspired desgin case studies. These will inform your very own original research project during the latter 6-8 weeks of the term.

Topics Covered

A wide-range of model systems may be studied which can be roughly grouped as below. Many of these could be appropriately cross-listed. It would be impossible to study all of these in depth during a 12 week term. We'll examine a good cross-section of these, and ***the systems on which we focus will be driven by student interest.*** Note that citation numbers refer to articles found in the separate References handout.

- *Optics*: Mantis shrimp eyes [4, 5, 6, 7, 8, 9, 10, 1, 11, 12, 13, 14, 15];
  Cephalopod Camouflage (octopus, squid, etc) [16, 17, 18, 19, 20, 21, 22, 23]
- *Thermal sensing*: Fire beetle [24, 25, 26, 27, 28, 29]
- *Fluid dynamics and propulsion*: Jellyfish propulsion [30, 31, 32, 33, 34, 35, 36, 2];
  Manta and Stingrays [37, 38, 39, 40, 41, 42]
  Bat wings/stretchable membranes [43, 44, 45, 46];

- *Electricity and Magnetism*: Shark prey sensing and Electric eels discharging [47, 48, 49, 50, 51, 52, 53, 54]
- *Materials*: Spider vibration-sensing hairs [55, 56, 57, 58]; Superhydrophobic diving bell spider [59, 60, 61]; Gecko feet [62, 63, 64, 65, 66]; Mussels threads [67]; Locust wings [68]; Impact-resistant conch shell[69]; Beaver-inspired wetsuits [70]; Porcupine-quills [71]; Chiton scale armor [72]; Acceleration-minimizing diving kingfisher beaks [73]
- *Emergent Swarm Behavior*: Fish school/bird flock steering and motion [74, 75, 76, 77]; Ant colonies and rafts [78, 79]
- *Plants*: Hogberries [80]; Cucumber tendrils [81]; Venus fly trap [82]
- *Bio-robots*: Insect biobots (cockroaches and flying beetles) [83, 84, 85, 86, 87, 88, 89, 90, 3, 91]; Soft-body robots (caterpillar) [92, 93, 94, 95, 96, 97]; Aquatic and aerial species[98, 99, 100, 101, 102, 103, 104]

Course Readings

We will read and discuss articles from a variety of sources, and journal articles will constitute our primary readings. Some will be recent publications, others will be classics in their field. Articles and other readings will provided in electronic format, linked on the course website.

Other sources

Two keep abreast of new developments, two excellent journals (my personal favorites) that you are encouraged to browse regularly are:

- *Biomemetics and Bioinspiration* (`http://iopscience.iop.org/1748-3190/`)
- *Journal of Experimental Biology* (`http://jeb.biologists.org/`)

Assignments and Grading

Homework

Homework will be assigned and collected on a weekly basis, planned for the first 4 weeks of the course. It will be typically be handed out at the end of class on Thursday and due at the beginning of class the following Thursday. Late homework will not be awarded credit unless it is the result of an officially excused absence. You are still invited to turn in unexcused late homework so that I can provide you with feedback. Please write homework in an orderly, legible manner. Your solutions should contain the following: a brief recapitulation of the problem; a brief (one or two sentence) explanation your analysis method; algebraic form of equations first, followed by plugging in of numbers; and the final result with a box around it.

Design/Research Project

The cornerstone of this course is the design/research project, which will last approximately 6–8 weeks. Working in interdisciplinary groups, students will design and execute an original research project, likely drawing inspiration from the material presented in the course. It is an opportunity for you to explore and invent. You will study a bioengineering problem of particular interest to you. *Topics can be wide-ranging, but must be approved by the instructor.* More details will be provided later in the term regarding the time-line and requirements of the project. A final written report and oral presentation is required for all students.

Grading

Letter grades will be assigned primarily on a numerical score basis, but will also be influenced by the instructor's subjective assessment of your overall competence and performance (more on this in a minute). The percentage of each component contributing to your grade is listed below.

Problem Sets	50%
In-class Discussion Participation	15%
Design Project Proposal and Initial Design Formulation	20%
Final Project: Choose Your Own Adventure:	15%
Total	100%

Your final state of competence is much more important than your overall numerical average. The subjective component is simply a mechanism by which—*when appropriate*—I can translate your final state into an appropriate letter grade. Throughout the term we will have many occasions to interact in the classroom. At the end of the 12 weeks together I gain a very good sense for placing students on the spectrum of "who really knows their stuff." Factors considered during this evaluation include, but are not limited to: class participation, intellectual growth, demonstrated overall integrity and competency in course work. Please know that this policy is in place neither to hurt nor help you. If you have any questions about this grading policy, please come talk to me.

COURSE POLICIES

Academic Honesty

According to the White Book[1], the Honor System is the "fundamental principle that a spirit of trust pervades all aspects of student life." The system is one of "mutual trust" which clearly establishes that "Students should do their own work, *represent themselves truthfully, and claim only that which is their own*" (emphasis added by JE). The system is not designed to "work against or frigthen" students, rather it was designed to allow students "unparalleled academic freedom."

You are expected to abide by the W&L Honor System at all times. Any suspected Honor Violation will be reported to the Executive Committee. In such an event, the instructor reserves the right to assign a grade of zero on that assingment and/or a failing grade for the course. (I believe in my heart that this policy will never ever come into play, but I am required to explicitly state it in the official course syllabus.) Specific policies regarding homework assignments, lab reports, and exams are described in detail below. If you are ever in doubt about whether an action is within bounds, please consult with me first.

Homework Policy

You are allowed and encouraged to discuss homework problems, but your written solutions must be generated by you alone. Consultation with solutions sets from last year of any kind is strictly forbidden.

Attendance Policy

Lectures

You are *strongly encouraged* to attend all lectures—it is highly likely you will find them to be beneficial aid to your learning. You are ultimately responsible for your own education. If you miss class for a legitimate reason (illness, family emergency, etc.) I will make every effort to help you get caught up as soon as possible. You must notify me *before class, in person or by phone,* to explain the circumstances of an excused absence. It is okay to leave a message. In the event of an unexcused absence (i.e., "Whoops, I slept in"; "I had paper due for another class"; "I left a day early for Spring Break", etc.), you are solely responsible for staying up to date with class notes and news (e.g., deviations from the calendar of topics covered, exam procedures, etc.).

Note on Athletics

Sanctioned athletic competitions, but not practice sessions, qualify as an excused absence. Please notify me of an athletic absence well in advance of the athletic event.

Figure 2: BioE is a No Texting Zone.

Electronic Devices and Texting

I would like to believe I am a pretty easy-going, congenial guy, but the one thing that absolutely drives me crazy is texting during class. So, thank you much in advance for powering down your cell phone/iPhone/Blackberry/Droid/whichever device, and for respecting the strict no-texting policy.

If you must have your phone on for tending to, say, a medical or family emergency, please inform me before the start of class.

Regarding the use of laptops in class, there shouldn't be any compelling reason to use a laptop during class. However, I do realize that some students prefer to take notes on them, and if you insist on electronic note-taking, please come talk to me. I will entertain any reasonable request (but do not promise to grant it).

Sick Day Policy

If you are feeling ill, please stay home, get some rest, get a friend to bring you notes from class and chicken soup and get better soon! I trust your judgment and do not require a doctor's note. (However, please remember to contact me regarding this absence.)

Academic Accommodations

Washington and Lee University makes reasonable academic accommodations for qualified students with disabilities. All undergraduate accommodations must be approved through the Title IX Coordinator and Director of Disability Resources, Elrod Commons 212, 458-4055. Students requesting accommodations for this course should present an official accommodation letter within the first two weeks of the term and schedule a meeting outside of class time to discuss accommodations. It is the students responsibility to present this paperwork in a timely fashion and to follow up about accommodation arrangements. Accommodations for test-taking must be arranged with the professor at least a week before the date of the test or exam, including finals.

Suggestions and Feedback

Suggestions for improvement, constructive criticism, and positive feedback are welcome at anytime. Please do not hesitate to approach me with any concerns you may have about this course. I take your feedback very seriously and will sincerely respond to all received comments. It is the main mechanisms by which the course will improve over time (sometimes instantaneously, when possible!).

[1]Full text of White Book available at `http://www.wlu.edu/x48217.xml`

References

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