the march of the bioengineers

https://youtu.be/6cBf-EGahvs

https://www.npr.org/templates/story/story.php?storyId=90014997

Introduction to Bioengineering
BIOE/ENGR.80
Stanford University

Spring 2020 Class Slides

Day 28 — recorded, last day
12 June 2020

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Week 10 last day, recorded

What have we learned

Resources going forward

Benedictions

What is our class about?

Students successfully completing BIOE/ENGR.80 will have a working understanding for how to approach the systematic engineering of living systems to benefit all people and the planet.

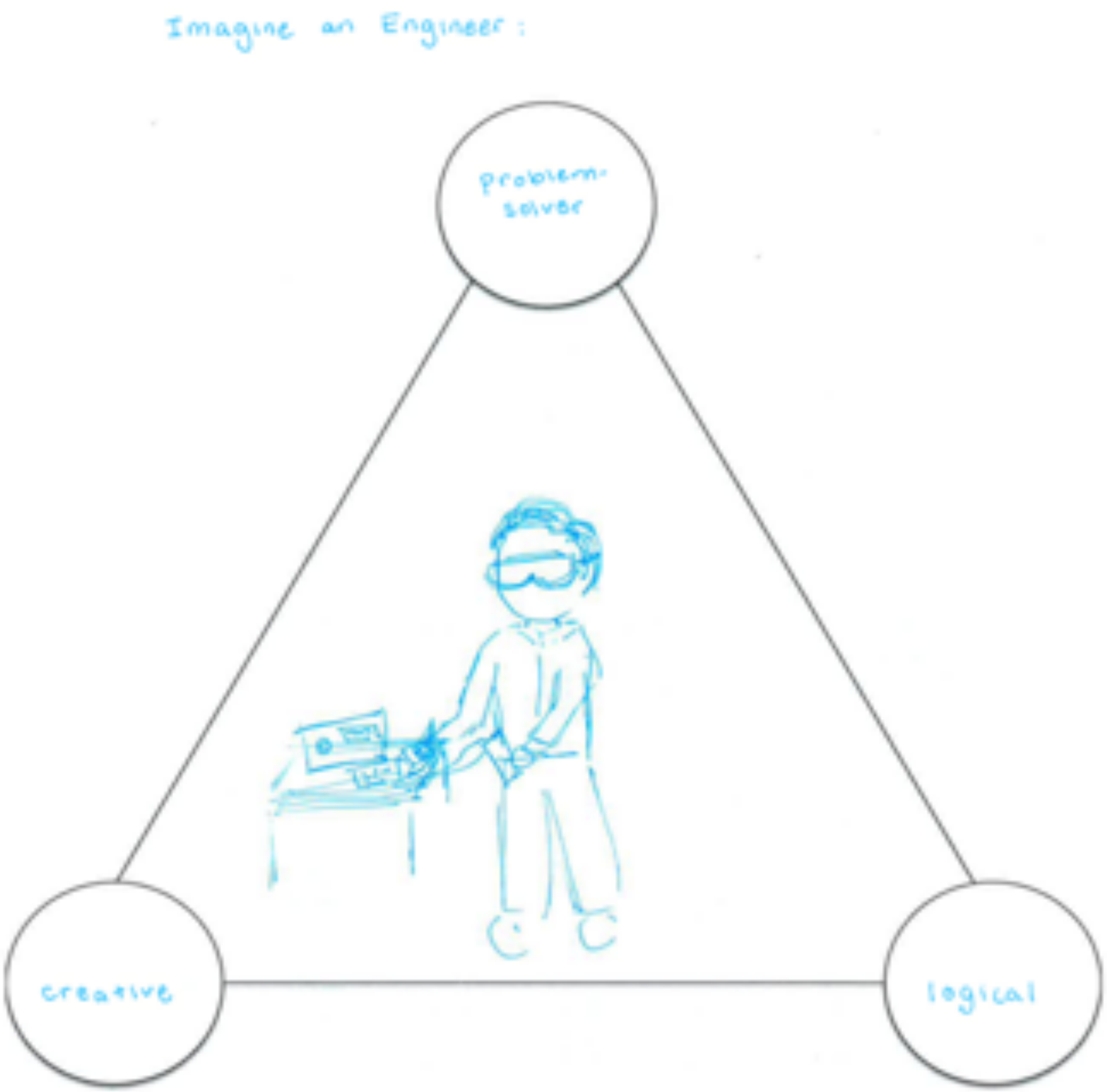
Our main goals for the quarter are:

(1) to help you learn ways of thinking about engineering living matter,

(2) for you to become more capable of learning and explaining bioengineering to yourself and others,

(3) for you to be capable of leading discussions of the broader ramifications of engineering the living world.

Imagine your bioengineer…



Course Companions!

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Core Course Companions and Curriculum Opportunities, Bachelor of Science in Bioengineering, Stanford University, 2018

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COLLECTION

Bioengineering

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Core Course Companions and Curriculum Opportunities

Bachelor of Science in Bioengineering

Stanford University

Source: snsf.stanford.edu

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Drs. Ahrar and Brand serve as **Science and Engineering Education Fellows** in the Department of Bioengineering. They work closely with faculty and lecturers under the guidance of the department's Undergraduate Curriculum Committee and with support from the office of the Vice Provost for Teaching and Learning. Ahrar and Brand's work is focused on realizing an active, effective, inclusive, and accessible curriculum for the discipline of Bioengineering.

PREFACE

Bioengineering as an academic practice has developed and renewed itself in three waves, each of which remain important and contribute to human flourishing. Historically, the first wave was powered by the application of established engineering methods to human needs, primarily found in the medical clinic or agricultural field. The second wave arose in response to the emergence of tools for collecting overwhelming amounts of quantitative data about living systems, initially DNA sequence-based but increasingly diverse in type and complexity. The third wave began with the invention of genetic engineering a generation ago and is accelerating towards realizing operational mastery of living matter from both an analytical and synthetic perspective.

Both the Stanford Bioengineering department and our undergraduate major arose after the emergence of all three waves. We started fresh in terms of organization and activities. We celebrate all opportunities to contribute to human flourishing, regardless of precedent or extrinsic framing. We both believe and can articulate that "enough is known already of the diverse applications of biology for us to recognize the birth of a coherent body of technique, which we call bioengineering... Whether living matter is used for manufacturing, medicine, music, or other purposes, the structure of bioengineering practice is much the same."[1] Additionally and practically, we can clearly describe how the physical materials bioengineers encounter and work with, biology, are qualitatively distinct from other types of materials now mastered by other fields of engineering, as is needed to frame a distinct discipline and resulting course of study.

Practically, our bioengineering major was approved in perpetuity by the Stanford University Faculty Senate in 2015. We engage ~100 students per year in our introductory courses. Each course is led by idiosyncratic faculty working alone or in pairs, all of whom enjoy full autonomy in terms of both course content and delivery. Our thriving department culture and collegiality allow us to coordinate and make adjustments over time. Collectively, our current offerings arose by implementing a third set of improvements to a second major revision of our program (i.e., ‘version 2c’). Having just completed the analysis presented herein, the first of its kind, we anticipate the next six months will involve discussions regarding whether a third revision to the program is warranted and practical (i.e., ‘version 3’).

Biology as both a science and technology is profound and practically powerful. Working together to learn how to best advance the practice of bioengineering education should be a collective endeavour. What should bioengineers learn? How should they learn it? Who should have the option of becoming a bioengineer? To enable all to learn and work together we are making all of our materials and analysis herein freely available. We ask only that you share your thoughts, critiques, suggestions, and wishes, in return. Let’s be great together!

BIOE.44, *Fundamentals for Engineering Biology Lab*
Student course companion link, (Page: 22 - 27)
Instructor opportunities for consideration link, (Page: 28 - 30)
Lab, 4 units

BIOE.101, *Systems Biology*
Student course companion link, (Page: 31 - 38)
Instructor opportunities for consideration link, (Page: 40 - 42)
Lecture, 3 units

BIOE.42, *Physical Biology*
Student course companion link, (Page: 43 - 50)
Instructor opportunities for consideration link, (Page: 51 - 53)
Lecture, 4 units

BIOE.123, *Bioengineering System Prototyping Lab*
Student course companion link, (Page: 54 - 61)
Instructor opportunities for consideration link, (Page: 62 - 65)
Lab, 4 units

BIOE.103, *Systems Physiology and Design*
Student Course Companion link, (Page: 66 - 78)
Instructor Opportunities for Consideration link, (Page: 79 - 81)
Lecture, 4 units

BIOE.131, *Ethics in Bioengineering*
Student Course Companion link, (Page: 82 - 89)
Instructor Opportunities for Consideration link, (Page: 90 -93)
Lecture, 3 units

BIOE.141A/B, *Senior Capstone Design*
Student Course Companion link, (Page: 94 - 102)
Instructor Opportunities for Consideration link, (Page: 103 - 104)
Lecture and Lab, 4/4 units

1. What will you learn in each course?

We use the concept of ***transfer functions*** to describe course objectives and outcomes. Each transfer function defines a relationship between ***inputs*** and ***outputs***. Here, inputs refer to student's wishes at the start of a course, and outputs are the knowledge and skills gained by the students via the course. ***Cofactors*** highlight additional skills and knowledge that will help you excel at the course. In practice you might have to spend more time on a course if you have limited experience and prior knowledge in a particular cofactor.

The transfer function tool is designed to help you answer the following questions:

1. What are the stated ***learning objectives*** for a course?
2. After the course what should I be able to do or accomplish?
3. Do I need to refresh or gain some adjacent skills or knowledge to do well in this course?
4. Why am I taking this course? What do I want to gain by successfully completing this course?

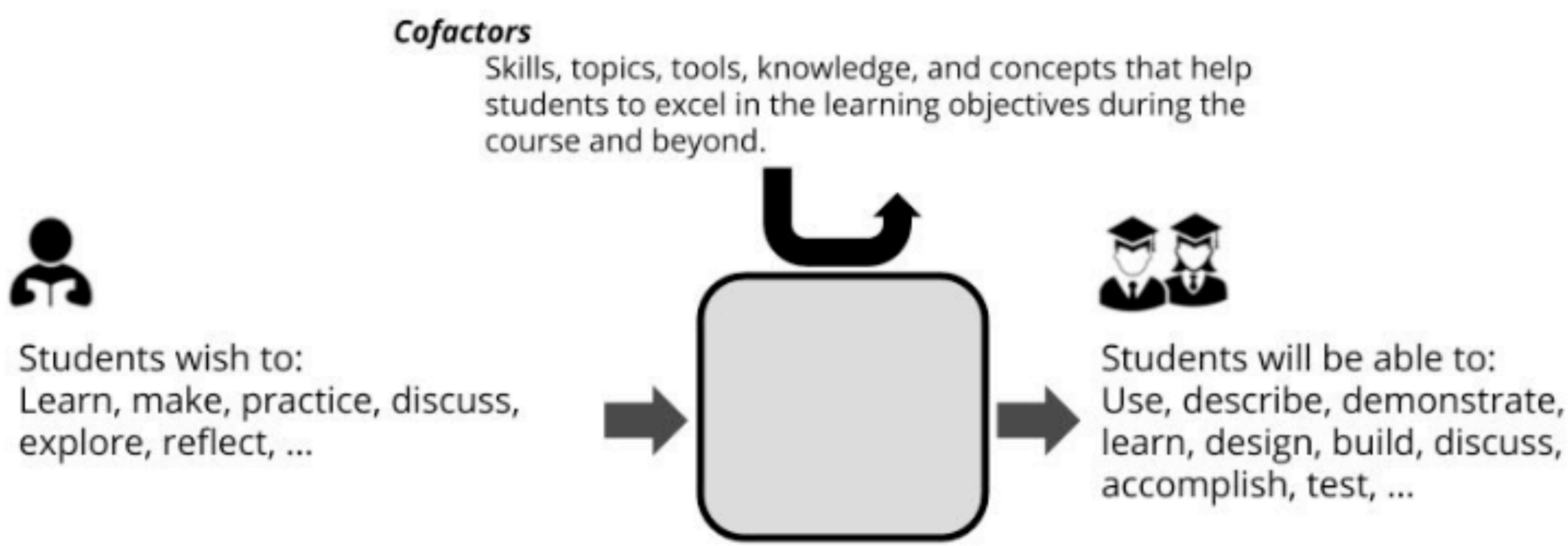


Figure.1. Transfer functions describe the expected change in a typical student in any given course. Stated differently, transfer functions summarize what you should expect to learn and accomplish via each course.

1. What will you learn in BIOE.44?

Students successfully completing the course will be able to rationally design a DNA "device" with a predicted function that can be measured. Students entering the course typically wish to learn to independently perform fundamental genetic engineering and synthetic biology techniques. BIOE.44's top level objectives, cofactors, and student expectations are described below *(Figure.44.1)*.

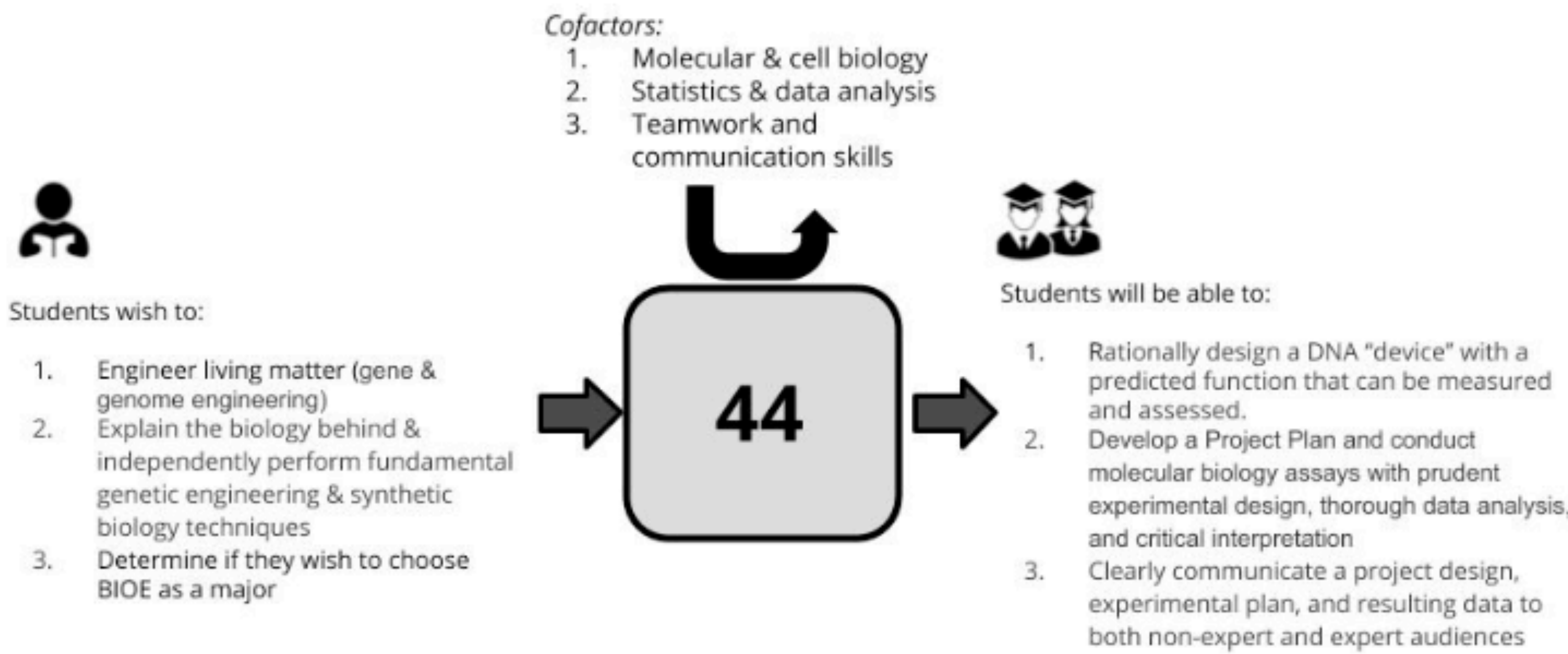


Figure. 44.1. The course provides students with a unique opportunity to practice engineering living matter using the Design, Build, Test framework.

2. What will you do in BIOE.44?

Most of your time and attention in this course will be focused on your project. Lectures and in-class activities will support you by providing you with necessary background knowledge and context. The course (including the lab, lectures, and activities) is divided into three main modules (*Figure.44.2)*: lab practices and tools for engineering living matter, engineering concepts applied to living matter, and beyond the lab (e.g., bioethics, safety and security in genetic engineering, and other topics in genetic engineering).

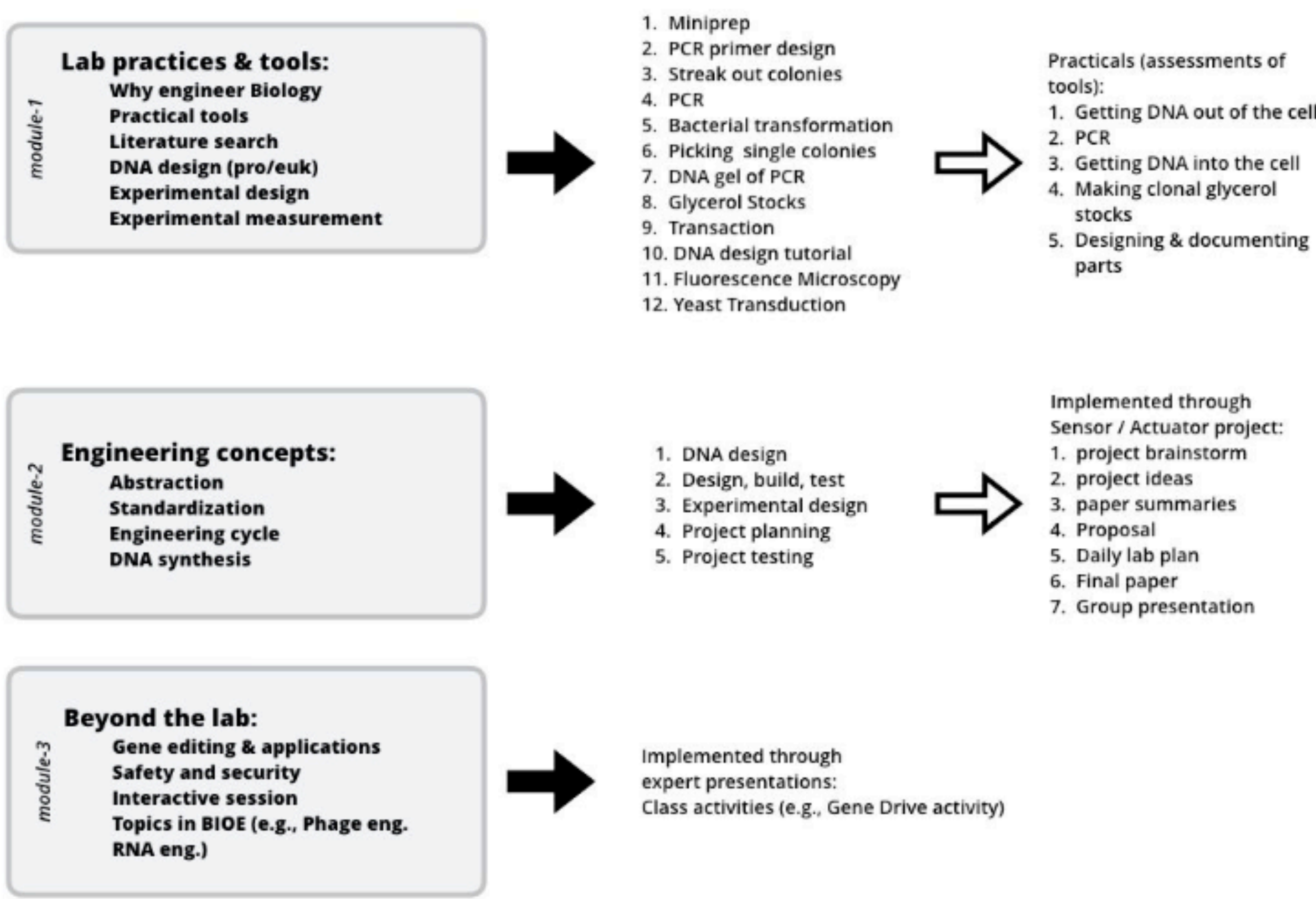


Figure. 44.2. The course provides students with a unique opportunity to practice engineering biology (design, build, and test) and to obtain essential lab skills.

3. Self-assessment before and after BIOE.44.

This self-assessment will help you prepare and keep track of what you will learn, or have learned, before and after the course. It is meant to help you reflect on your own growth and can be a starting point for reviewing the material.

Dear BIOE.44 student: Estimate/score your ability on each learning goal /skill before and after the class.

Range 0 = I don't know what this means - No ability
1 = Basic understanding / ability - words are familiar
2 = I have done this in class, problem sets, or activities
3 = I can confidently and independently accomplish this goal
4 = I can help other learners / can fully explain
5 = I can improve the approach (method) / can do better

Goal	Before	After
Rationally design (and document) a DNA device with a predicted function that can be measured/assessed.		
Explain the biology behind fundamental genetic engineering and synthetic biology techniques.		
Develop a Project Plan and conduct molecular biology assays with prudent experimental design (thorough data analysis, and critical interpretation).		
Practice design, build, test applied to the engineering of living matter.		
Clearly communicate a project design, experimental plan, and resulting data to non-expert and expert audiences.		
Describe what it means to engineer biology.		
Critically discuss opportunities, challenges, and ramifications at the emerging frontiers of engineering biology (e.g., gene drives).		
Get DNA out of cells.		
Conduct PCR and gel electrophoresis.		
Get DNA into cells.		
Create clonal glycerol stocks.		
Keep a lab notebook which includes project plans, experimental design, and experimental results.		

4. Tips for success

Here are suggestions from previous students and TAs to help you in the course:

1. **Invest time and think carefully about your project plan**. Use and update the project plan as you progress through your experiments.

2. Many students worry about lacking fundamental lab skills at the start of the course. **You will learn** and practice these essential skills throughout the course. You will also master why and how each technique works. **Make sure to take advantage of the resources** (teaching team, your peers, and lab space and resources) that are available to you throughout the course.

3. **Organize** your data, graphs, and data visualization as you work through your project. Don't wait until the final presentation. By the end of the quarter, you want to be able to clearly communicate your team's goals and accomplishments.

4. **Work on your presentation and report throughout the quarter**. The project reports take longer than your initial estimates. Please start early and remain engaged throughout the class.

5. **Actively communicate** with your team and the teaching team. Take advantage of the expertise that the teaching team brings to help you and your project. Make sure to learn why you are doing an activity.

7. **Be a good team member and a lab citizen**.

Goals & Topics

We present a comprehensive list of goals and topics for the undergraduate major in Bioengineering at Stanford. These goals and topics define the "minimum set" of what every student earning a Bachelor's degree from our program should be able to do. As such, these goals and topics form the basis of our core curriculum, and our assessments of the students and the undergraduate program overall.

How the words "GOALS" and "TOPICS" are used in this document:
We use the words "goals" and "topics" in a specific sense… successful graduates will be able to achieve or apply the stated goals via proficiency in the noted topics. In some cases specific "tools" are incorporated within or as topics. Here are three examples:

- Successful graduates are able to "*Understand what makes living matter unique as an engineering substrate.*" To do so they can "*Describe and utilize evolution.*"

- Successful graduates are able to "*Apply math to model and analyze biological systems*."
  To do so they have obtained mastery of "*Linear Algebra.*"

- Successful graduates are able to "*Practice and serve as an effective leader.* " To do so they can "*Identify and set goals and milestones at the start and throughout a project or activity.*"

Topics and Goals in Biology

Category	Goal	Topic
Biology	Understand what makes living matter unique as an engineering substrate	Describe living matter, what is it and how is it different from other types of materials? Experience or model living matter across various time and length scales Describe and utilize evolution
	Fundamental mastery of basic life processes -- understand mechanisms for storing and processing energy, information, and matter in living systems.	Describe how energy is stored and processed in living systems Describe how information is encoded, processed, and transmitted within and among living systems Describe how living systems interact with and arrange atoms and molecules
	Engage in systems thinking sufficient to develop empathy for how living systems will or may behave, and to anticipate outcomes of making changes to living systems or their environments.	Navigate through the organization of living matter across scales: molecular, cellular, tissue, organs, and systems Describe the action of biological systems across various scales. Examples include: genetic networks, regulatory motifs, cascade reactions, cell-cell signaling (such as neuronal signaling) Explain homeostasis and systems regulation Explain what goes awry in different pathologies
	Apply engineering and scientific habits of mind to biology	Design experiments, obtain measurements, build prototypes, and develop models with or of living systems Develop a habit of mind to approach biology mathematically and quantitatively

Topics and Goals in Math & Computation

Category	Goal	Topic
Math	Develop a strategic habit of mind towards interpreting and addressing real-world situations, challenges, and opportunities	Logic Optimization
	Apply math to model and analyze biological systems	Calculus ODEs Linear Algebra Probability Vector Calculus
	Describe the results and outcomes of experiments and models	Probability Statistics

Category	Goal	Topic
Compute	Approach and solve complicated problems via systematic engineering approaches	**Primary:** Modular design and functional abstraction supporting reliable reuse of work products **Secondary:** Task automation; converting physical problems into computational problems; embedded and cloud computing
	Strategize design, build, test, and assess to successfully engineer computer software	Data types and data structures Object-oriented programming (defining operations) Numerical techniques Debugging skills Testing approaches Machine learning approaches and tools
	Develop a repository of good practices when developing code and scripts	Tests and edge cases Code documentations Tools for coding collaboration
	Obtain practical computing skills	**Primary:** Python (or Matlab) R PyMOL Embedded software (Arduino, Raspberry Pi) Command line programming CAD software for prototyping (Onshape) **Secondary:** Version control tools (Git) Labview (or equivalent) Finite element analysis (Comsol)

Topics and Goals in Physics & Chemistry

Category	Goal	Topic
Physics	Understand and predict the spontaneous behaviors of living systems	Energy (forms of energy and conservation of energy) Statistical Mechanics (specifically enumeration of system states)
	Predict the emergence of order in biological systems	Units and dimensional analysis Bionumbers & order of magnitude estimations Classical Mechanics Statistical Mechanics Electricity and Magnetism Light and optics
	Use standards and metrology in the context of biology	Quantitation, metrology, and modeling

Category	Goal	Topic
Chemistry	Understand and predict what happens in living systems	Laws of Thermodynamics Kinetics and rate laws Reactions and stoichiometry The Ideal Gas Law Chemical Equilibrium and response to perturbation Types of reactions Metabolism (harnesses chemical & electrical gradients via redox reactions)
	Identify opportunities and approaches for engineering of and with living matter	Enzymatic reactions and Michaelis-Menten Kinetics Metabolic pathways (molecules and energy) Types of chemical bonds Molecules, Molecular Orbital Theory Reaction mechanisms in organic molecules

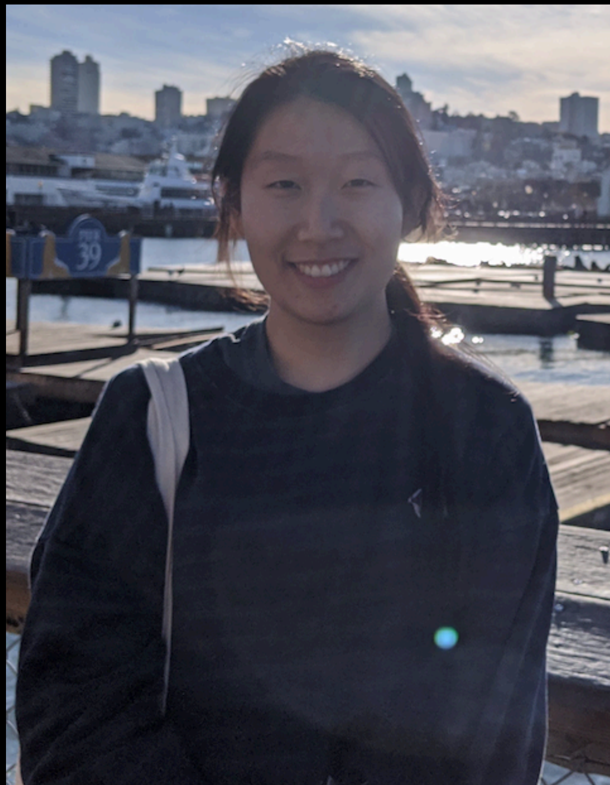
Topics and Goals in Engineering & Science Fundamentals

Category	Goal	Topic
Engineering and Science Fundamentals	Navigate through and practice the engineering cycle	Design, build, test, and assess iteratively as an engineering approach and practice Utilize abstraction as a tool to manage complexity Systems thinking, systems integration, and approaches (including foundations of control theory) Metrology & Standardization (reliable reuse of materials, measurements, and models sufficient to enable coordination of labor) Tool development (make engineering of living matter easier)
	Apply the scientific method	Critically analyze assumptions, evidence, and draw conclusions Quantitatively measure and validate systems Experimental design (null hypotheses, positive and negative controls)
	Identify societal or technical needs, gaps, and ongoing challenges that can be addressed via bioengineering	Practice needs-finding (gap analysis) Utilize primary sources to determine the frontier of knowledge
	Define a design for an engineering project with clear and objective goals	Create design input requirements and design output specifications Communicate a design in context-appropriate media (e.g., block diagrams, flow diagrams, circuit diagrams, etc.) Quantitatively specify verification and validation tests for a design

Topics and Goals in Engineering within Society

Category	Goal	Topic
Engineering within Society	Contribute and work effectively as a member of a team	Organize, build, or lead teams (via defined rules and roles) Evaluate contributions and effectiveness, both as a team and as individuals
	Practice and serve as an effective leader	Apply choice and agency at the start and throughout a project or activity Identify and set goals and milestones at the start and throughout a project or activity
	Consider ethics in personal conduct and ethical aspects or effects of tools and technology	Applied ethics Culture and ethics Ethical frameworks
	Identify and empathize with diverse stakeholders	Design for an equitable and just future Empathy for various stakeholders (listening skills) Empathy for other disciplines (e.g., how scientists approach their field and how to learn from them)
	Communicate with experts and non-experts on technical projects in bioengineering	Written reports Oral presentations Visual communication of data and results Seek, receive, and incorporate feedback
	Act as a self-initiated learner	Identify and set goals for learning Practice transfer Assess their own knowledge level (via reflection) and identify potential gaps Plan and adjust a learning approach

Benediction & Gratitude



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