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Synthetic Biology

By Wendy Wooten, ABE Greater Los Angeles Area

ABE Master Teacher Fellowship Program

AMGEN® Biotech Experience

Scientific Discovery for the Classroom

The curriculum projects designed by the 2021–22 ABE Master Teacher Fellows are a compilation of curricula and materials that are aligned with Amgen Biotech Experience (ABE) and prepare students further in their biotechnology education. These projects were created over the course of a 1-year Fellowship in an area of each Fellow's own interest. Each is unique and can be adapted to fit the needs of your individual classroom. Objectives and goals are provided, along with expected outcomes. Projects can be used in conjunction with your current ABE curriculum or as an extension.

As a condition of the Fellowship, these classroom resources may be downloaded and used by other teachers for free. The projects are not edited or revised by the ABE Program Office (for content, clarity, or language) except to ensure safety protocols have been clearly included where appropriate. We are grateful to the ABE Master Teacher Fellows for sharing their work with the ABE community.

If you have questions about any of the curriculum pieces, please reach out to us at ABEInfo@edc.org, and we will be happy to connect you with the author and provide any assistance needed.

AMGEN® Biotech Experience

Scientific Discovery for the Classroom

Greater Los Angeles

ABE Master Teacher Fellowship

Synthetic Biology

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SUMMARY

Classroom Curriculum: Students will investigate: 1) What is synthetic biology? 2) How can synthetic biology be used to address current real-world problems? 3) What are the ethical considerations for synthetic biology? 4) How can synthetic biology be performed in the classroom lab? 5) If I were a research scientist, how would I apply synthetic biology to solve a current real-world problem?

Teacher PD: Teachers will learn background on synthetic biology, its potential applications, the outlook on its potential impact on scientific and technological discoveries, and how to implement a classroom curriculum to share with and inspire their students.

Estimated Project Duration: (# weeks/class periods)

Classroom Curriculum: Variable depending on teacher goals and depth of coverage; 1–3 weeks, 5–15 lessons

Teacher PD: Variable depending on the extent of lab engagement; 1–2 days

Student Understandings/Big Ideas:

- **Synthetic biology** is a new interdisciplinary area that involves the application of engineering principles to biology.
- **Synthetic biology** is the design and construction of new biological entities such as enzymes, genetic circuits, and cells or the redesign of existing biological systems.
- **Synthetic biology** can be thought of as a biology-based "toolkit" that uses abstraction, standardization, and automated construction to change how we build biological systems and expand the range of possible products.

- **Synthetic biology** has been described as a "disruptive technology at the heart of the so-called *bioeconomy*, capable of delivering new solutions to global healthcare, agriculture, manufacturing, and environmental challenges." *Future Trends in Synthetic Biology—A Report*, *Frontiers in Bioengineering and Biotechnology*

Student Understandings/Learning Outcomes:

- Students will understand, be able to describe and be able to apply basic concepts and scientific practices of the emerging field of synthetic biology.
- Students will create a biological / genetic circuit known as a Repressilator that is analogous to an electronic blinking light circuit to sequentially turn on and turn off the expression of the green fluorescent protein GFP gene.
- Students will perform laboratory techniques using synthetic biology technologies to gain an in depth understanding of the mechanisms which underly applications in this field.
- Students will apply synthetic biology as a methodology to address a current authentic issue facing our world.

Assessments	Standards
Pre-Assessment survey on prior knowledge of synthetic biology and its applications	**HS-LS1-1.** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
Formative assessment quizzes on basic concepts of synthetic biology, including concepts of biological parts/ components, engineering design, mathematical and computer science modeling and programming, and applications of synthetic biology	**HS-LS1-1.** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Assessments	Standards
Summative assessment of student Repressilator models created by applying synthetic biology to produce a biological / genetic circuit that successively turns GFP gene expression on and off	**HS-LS1-1.** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. **HS-PS3-3.** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
Formative assessment of synthetic biology laboratory investigations communicated in scientific laboratory reports	**HS-LS1-3.** Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design. **HS-LS1-1.** Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.
Formative assessment on the bioethics of synthetic biology	**HS-ESS3-2.** New technologies can have deep impacts on society and the environment, including some that were not anticipated.
Summative assessment of student understanding and application of synthetic biology principles communicated in written grant proposals to address current authentic global issues	**HS-LS1-1.** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. **HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. **HS-ETS1-1.** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. **HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more

Assessments	Standards
	manageable problems that can be solved through engineering. **HS-ETS1-4.** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem. **HS-LS2-7.** Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. **HS-LS4-6.** Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. Source: *Next Generation Science Standards: For States, By States*

Opening "Hook": How can we use biological science and biotechnology by applying the engineering design process to address current global challenges? Students will create lists of real-world problems and issues that are important to them which could possibly be solved using biological intervention / biotechnology. Students will share their lists in small groups and then with the class to create a top 10 list that the class would want to address if provided the resources necessary.

Prior Knowledge and Skills:

Students need to know:

- the Central Dogma (DNA → RNA → protein)
- basic concepts of transcriptional regulation (transcription factors, activators, and repressors)
- cell structure and functions of cellular components
- basic concepts of feedback regulation

Cultural Relevancy and Personal Connections:

The driving question of this curriculum asks students to identify global problems and issues that could be addressed by biological interventions or biotechnology which they feel are the most important and relevant challenges facing the world today, knowing that they will be the generation which will need to provide the solutions.

Learning Activities at a Glance:	
Activity 1: Preassessment survey of prior knowledge on synthetic biology and engineering design process	*Materials and Resources Needed:* Preassessment survey
Activity 2: Creation of class top 10 list of current global issues/problems that can be solved with biological intervention / biotechnology	*Materials and Resources Needed:* Classroom discussion and share out
Activity 3: What is synthetic biology and how can it address current global issues/problems? Teacher-directed and independent student research	*Materials and Resources Needed:* Classroom AV presentation platform, classroom internet search devices; Synthetic Biology Explained https://www.youtube.com/watch?v=rD5uNAMbDaQ; Future Trends in Synthetic Biology—A Report https://www.frontiersin.org/articles/10.3389/fbioe.2019.00175/full; How to Engineer Biology (*Scientific American*) https://blogs.scientificamerican.com/observations/how-to-engineer-biology/
Activity 4: Formative assessment on synthetic biology and its applications	*Materials and Resources Needed:* Formative assessment
Activity 5: Design a GFP transcriptional oscillator (Repressilator)–creation of a genetic circuit to turn GFP on and off in a synchronized repeated cycle using gene	*Materials and Resources Needed:* Review regulation of gene expression using transcriptional repressors http://www.sci.sdsu.edu/~smaloy/MicrobialGenetics/topics/regulation/repressors.html Repressilator 1D https://ccl.northwestern.edu/netlogo/models/Repressilator1D
Activity 6: Summative assessment Repressilator model summary with justification / evidence	*Materials and Resources Needed:* Model Summary with Justification / Evidence Guidelines

Activity 7: Laboratory investigations in synthetic biology	*Materials and Resources Needed:* Carolina Biological BioBuilder labs (Eau That Smell Kit; Golden Bread Transformation Kit; Golden Bread PCR; iTune Device Kit; What a Colorful World Kit; pClone: Exploring Promoters with Synthetic Biology Kit)
Activity 8: Formative assessment - Laboratory written report	*Materials and Resources Needed:* Laboratory Written Report Guidelines
Activity 9: Research bioethics of synthetic biology	*Materials and Resources Needed:* The Ethics of Synthetic Biology and Emerging Technologies https://www.genome.gov/27542921/the-ethics-of-synthetic-biology-and-emerging-technologies
Formative assessment–Essay on the bioethics of synthetic biology	*Materials and Resources Needed:* The Ethics of Synthetic Biology and Emerging Technologies https://www.genome.gov/27542921/the-ethics-of-synthetic-biology-and-emerging-technologies
Activity 10: Grant proposal to address a current global issue of student's choice using synthetic biology	*Materials and Resources Needed:* Internet search device for independent research; Grant Proposal Guideline
Summative assessment–Written grant proposal of synthetic biology application to address a current global issue	*Materials and Resources Needed:* Grant Proposal Guidelines; industry professional panel to judge grant proposals

Activity 1: Preassessment survey of prior knowledge on synthetic biology and engineering design process

Overview: Students are given a preassessment to assist both teacher and students in determining initial level of understanding and content areas that need review

Learning Goals: Identification of what students know and what they still need to learn, the type of intervention that may be most appropriate, a sense of the disposition of students, and, after the post-assessment, how effective the lessons were to promote student learning

Key Vocabulary: algorithm, biobricks; biohacking; biofuel; biopharmaceutical; biosensor; chassis; cell-free system; codon; CRISPR-Cas9; commodity chemical; computer aided design CAD; device; engineering design process; gene expression; genome; genetically modified organism GMO; iGEM; International Gene Synthesis Consortium IGSC; *in vitro; in vivo;* Kozak sequence; DNA library; metabolite; mutant; operon; origin of replication ORI; open source; synbio part; promoter; quorum sensing; recombinant DNA; ribosome binding site RBS; synthetic biology; system; transformation; transgenic; vector

Materials and LabXchange Pathway(s): ABE pathway supportive videos, interactives, texts, etc.

Teacher Preparation: none

Lab Safety Considerations: none

Sequence

Activity Description	*Time*	*Materials*
1. Administer preassessment	15–20 min.	Preassessment
2. Student reflection, class share out on preassessment results	10–15 min.	Group configurations

Activity 2: Individual and class research–What is synthetic biology and how can it improve human life and/or our world?

Overview: Students will research the topic of synthetic biology and its applications using both provided and independently gathered sources which they discuss and summarize in small groups, and then share out to create a classroom description of synthetic biology and how it is impacting a variety of global issues.

Learning Goals: Students develop an understanding of the field of synthetic biology, how it applies the engineering design process to utilize characterized biological parts / biobricks to create desired functional devices that are incorporated as genetic systems housed in a living chassis to solve a defined problem through construction, testing and analysis.

Assessed Outcome: Students are expected to understand synthetic biology so they can explain it to the public.

Key Vocabulary: abstraction; activator; biobricks; bottom-up design; central dogma; chassis; codon optimization; computer aided design CAD; consensus; conserved sequence; constitutive promoter; deterministic model; device; feedback; functional genomics; gene synthesis; genome engineering; graphic user interface GUI; holoenzyme; iGEM; *in silico, in vitro, in vivo*; inducible promoter; intergenic; inverter; logic gates (AND, OR, NOT, NAND, etc.); model; modularity; next generation sequencing NGS; open reading frame ORF; operator; operon; palindrome; parsimony; part; polymerase chain reaction PCR; primer; promoter; receiver; regulatory region; reporter; repressilator; repressor; restriction enzyme; ribosome binding site RBS; sender; shotgun sequencing; standardization; genetic switch; synthetic biology; system; terminator; toggle switch; top-down design

Materials and LabXchange Pathway(s):

- Introduction to Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:51875b21:video:1
- Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:773ba7b9:lx_simulation:1
- Cellular Chassis
  https://www.labxchange.org/library/items/lb:LabXchange:a48ca57a:video:1
- Engineering Gene Networks–Integrating Synthetic Biology and Systems Biology
  https://www.labxchange.org/library/items/lb:LabXchange:ac5903c2:video:1
- Synthetic Biology Interactive Timeline
  https://www.labxchange.org/library/items/lb:LabXchange:2b8a3371:lx_simulation:1
- Introduction to Synthetic Biology and Metabolic Engineering
  https://www.labxchange.org/library/items/lb:LabXchange:5129aada:video:1

- Abstraction–Teacher slides https://www.labxchange.org/library/items/lb:LabXchange:cf0c7062:lx_document:1

Teacher Preparation:

- Synthetic Biology PD
- *Synthetic Biology–A Primer* by Baldwin et al.
- *BioBuilder–Synthetic Biology in the Lab* by Kuldell et al.
- *BioBuilder for Teachers* https://biobuilder.org/education/for-teachers/
- Synthetic Biology and the High School Curriculum https://openwetware.org/wiki/Synthetic_Biology_and_the_High_School_Curriculum

Lab Safety Considerations: None

Sequence

Activity Description	*Time*	*Materials*
1. Individual student research and summary on synthetic biology overview	2 hrs	Synthetic Biology https://www.ted.com/speakers/lynn_rothschild Synthetic Biology Explained https://www.youtube.com/watch?v=rD5uNAMbDaQ What Is Synthetic Biology https://www.youtube.com/watch?v=H_CLySMFP38 Synthetic Biology Principles https://www.youtube.com/watch?v=ku9_0NIhRPc Future Trends in Synthetic Biology—A Report Frontiers in Bioengineering and Biotechnology | www.frontiersin.org
2. Group discussions and class share outs on synthetic biology; KWHL chart, categorize and prioritize student/group questions	1 hr	KWHL https://www.youtube.com/watch?v=ch6rYJheGHU

Activity Description	*Time*	*Materials*
3. In-depth student research and summary on synthetic biology	3 hrs	Synthesizing Change https://www.youtube.com/watch?v=QfLtQwiQ_7s Synthetic biology - what should we be vibrating about?: Drew Endy at TEDxStanford (Bioethics) https://www.youtube.com/watch?v=rf5tTe_i7aA TEDxCaltech - J. Craig Venter - Future Biology https://www.youtube.com/watch?v=HdgfzdlgUHw Synthetic biology advances and applications in the biotechnology industry: a perspective Journal of Industrial Microbiology & Biotechnology (2018) 45:449–461 https://doi.org/10.1007/s10295-018-2056-y How to Engineer Biology By Vijay Pande on November 8, 2018 Scientific American https://blogs.scientificamerican.com/observations/how-to-engineer-biology/ Why Synthetic Biology is the Field of the Future https://www.pbs.org/wgbh/nova/article/why-synthetic-biology-is-the-field-of-the-future/
4. Group and class share out and summary of synthetic biology	1 hr	Group configurations

Activity 3: Synthetic biology challenge from industry professional

Overview: Industry professional presents their research in synthetic biology, provides background knowledge, and presents a design challenge for students to apply principles of synthetic biology. (For the Biomedical Science Pathway at Reseda Charter High School, Dr. Leonardo Morsut, professor of stem cell biology and regenerative medicine at the Keck School of Medicine of USC, presents his work to invent and use synthetic biology tools to control multicellular behaviors, with a special focus on stem cells and regenerative medicine applications. He covers basic genetic circuits using parts to create devices within a mammalian chassis–e.g., synthetic notch signaling for cell sensing and response https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4752866/), and then challenges students to apply their knowledge to design a genetic Repressilator.)

Learning Goals:

Students will understand how synthetic biology can be applied in an authentic research project by an industry professional who will provide a design challenge related to their research–learning goals will be specific based on the articulation with an industry professional.

RCHS Biomedical Science Pathway: Students will read a primary research paper to gain insight into the design process used to create and characterize a synthetic biology system; students will apply their knowledge and understanding to solve a basic challenge to create a genetic circuit known as a Repressilator that results in the sequential activation and repressions of GFP production, analogous in electrical circuits to a blinking green light.

Assessed Outcome: These will be specific based on the particular articulation with an industry professional. RCHS Biomedical Science students will produce a genetic circuit using transcription factors and repressors that sequentially turns the expression of the GFP gene on and then off, e.g., a Repressilator circuit. Students will be able to describe and justify their design, represent their design using logic gates, and describe a mathematical model of the system output using linear algebra.

Key Vocabulary (will be specific based on the industry professional articulation): activator; biobrick; chassis; constitutive promoter; device; feedback; genome engineering; graphic user interface GUI; inducible promoter; inverter; ligand; ligand receptor; logic gates (AND, OR, NOT, NAND, etc.); model; modularity; Notch signaling pathway; part; promoter; receiver; regulatory region; reporter; repressilator; repressor; sender; genetic switch; synthetic biology; system; toggle switch; transcriptional regulator

Materials and LabXchange Pathway(s):

- Introduction to Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:51875b21:video:1
- Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:773ba7b9:lx_simulation:1
- Cellular Chassis
  https://www.labxchange.org/library/items/lb:LabXchange:a48ca57a:video:1
- Engineering Gene Networks–Integrating Synthetic Biology and Systems Biology
  https://www.labxchange.org/library/items/lb:LabXchange:ac5903c2:video:1
- Synthetic Biology Interactive Timeline
  https://www.labxchange.org/library/items/lb:LabXchange:2b8a3371:lx_simulation:1
- Introduction to Synthetic Biology and Metabolic Engineering
  https://www.labxchange.org/library/items/lb:LabXchange:5129aada:video:1
- Abstraction–Teacher slides
  https://www.labxchange.org/library/items/lb:LabXchange:cf0c7062:lx_document:1

Teacher Preparation:

- Synthetic Biology PD
- Content background relative to industry professional articulation

Lab Safety Considerations: None

Sequence

Activity Description	*Time*	*Materials*
1. Introduction of industry professional and overview of their synthetic biology research	1.5 hr	In person or virtual presentation
2. Background information by industry professional in preparation for synthetic biology design challenge	1.5 hrs	In person or virtual presentation
3. Student design of solution to synthetic biology challenge	2 hrs	Internet access
4. Student share out of synthetic biology challenge designs with industry professional	1 hr	Group configurations

Activity 4: Summative assessment quiz on synthetic biology concepts

Overview: Effectiveness of synthetic biology curriculum and assessment of student learning and disposition change will be assessed

Learning Goals: Students develop an understanding of underlying concepts, the engineering process, logic gates and abstraction, and mathematical modeling that are essential components of synthetic biology

Assessed Outcome: Effectiveness of synthetic biology curriculum and assessment of student learning and disposition change will be quantified and reviewed

Materials and LabXchange Pathway(s):

- Introduction to Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:51875b21:video:1
- Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:773ba7b9:lx_simulation:1
- Cellular Chassis
  https://www.labxchange.org/library/items/lb:LabXchange:a48ca57a:video:1
- Engineering Gene Networks–Integrating Synthetic Biology and Systems Biology
  https://www.labxchange.org/library/items/lb:LabXchange:ac5903c2:video:1
- Synthetic Biology Interactive Timeline
  https://www.labxchange.org/library/items/lb:LabXchange:2b8a3371:lx_simulation:1
- Introduction to Synthetic Biology and Metabolic Engineering
  https://www.labxchange.org/library/items/lb:LabXchange:5129aada:video:1
- Abstraction–Teacher slides
  https://www.labxchange.org/library/items/lb:LabXchange:cf0c7062:lx_document:1

Teacher Preparation:

- Synthetic Biology PD
- *Synthetic Biology–A Primer* by Baldwin et al.
- *BioBuilder–Synthetic Biology in the Lab* by Kuldell et al.
- *BioBuilder for Teachers* https://biobuilder.org/education/for-teachers/
- Synthetic Biology and the High School Curriculum
  https://openwetware.org/wiki/Synthetic_Biology_and_the_High_School_Curriculum

Lab Safety Considerations: None

Sequence

Activity Description	*Time*	*Materials*
1. Delivery of synthetic biology summative assessment quiz	1 hr	Synthetic Biology summative assessment quiz
2. Student reflection and review of synthetic biology summative assessment quiz	1 hr	Internet access

Activity 5: Synthetic biology laboratory exercises

Overview: Students will perform synthetic biology investigations: BioBuilder labs - Eau That Smell; Golden Bread; iTune Device; Picture This; What a Colorful World

Learning Goals: Students will gain an understanding of concepts and laboratory skills in synthetic biology

Assessed Outcome: Students will create written laboratory reports that demonstrate understanding of laboratory applications of synthetic biology

Key Vocabulary: standardization; abstraction; synthesis; growth curve, lag phase, log phase, stationary phase; promoter; genetic inverter; NOT logic gate; chassis engineering; positive control; negative control; β-carotene biosynthesis genes; mean time to failure; redundancy; codon shuffling; genetic complementation; modularity; insulation; measurement; ribosome binding site RBS; biosensor; emergent behavior

Materials and LabXchange Pathway(s):

- Teacher Lab Manuals iTune Device
  https://www.labxchange.org/library/items/lb:LabXchange:7d90cde9:lx_document:1
- What a Colorful World
  https://www.labxchange.org/library/items/lb:LabXchange:aef381d6:lx_document:1
- Science of Golden Yeast
  https://www.labxchange.org/library/items/lb:LabXchange:c157dd66:lx_document:1
- Engineering Golden Yeast
  https://www.labxchange.org/library/items/lb:LabXchange:05007bbf:lx_document:1
- Eau That Smell
  https://www.labxchange.org/library/items/lb:LabXchange:9b81bbc4:lx_document:1

Teacher Preparation:

- BioBuilders Instructor Lab Manuals: Synthetic Biology PD
- *Synthetic Biology–A Primer* by Baldwin et al.
- *BioBuilder–Synthetic Biology in the Lab* by Kuldell et al.
- BioBuilder for Teachers

Lab Safety Considerations:

- Biomanufacturing and Synthetic Biology OSHA Safety protocols
  https://www.cdc.gov/niosh/topics/advancedmnf/biomnf.html

Sequence

Activity Description	*Time*	*Materials*
1. BioBuilders Lab Eau That Smell	1 day	Carolina Biological BioBuilders Lab kit
2. BioBuilders Lab Golden Yeast	1 day	Carolina Biological BioBuilders Lab kit
3. BioBuilders Lab iTunes Device	1 day	Carolina Biological BioBuilders Lab kit
4. BioBuilders Lab What a Colorful World	1 day	Carolina Biological BioBuilders Lab kit

Activity 6: Synthetic biology laboratory report formative assessment

Overview: Students create written reports of synthetic biology laboratory investigations

Learning Goals: Students will learn the experimental designs and laboratory skills used in synthetic biology

Assessed Outcome: Laboratory reports will demonstrate student understanding of underlying concepts, experimental design, and laboratory skills used in synthetic biology investigations

Key Vocabulary (dependent on lab(s) performed): standardization; abstraction; synthesis; growth curve, lag phase, log phase, stationary phase; promoter; genetic inverter; NOT logic gate; chassis engineering; positive control; negative control; β-carotene biosynthesis genes; mean time to failure; redundancy; codon shuffling; genetic complementation; modularity; insulation; measurement; ribosome binding site RBS; biosensor; emergent behavior

Materials and LabXchange Pathway(s):

- Teacher Lab Manuals iTune Device
  https://www.labxchange.org/library/items/lb:LabXchange:7d90cde9:lx_document:1
- What a Colorful World
  https://www.labxchange.org/library/items/lb:LabXchange:aef381d6:lx_document:1
- Science of Golden Yeast
  https://www.labxchange.org/library/items/lb:LabXchange:c157dd66:lx_document:1
- Engineering Golden Yeast
  https://www.labxchange.org/library/items/lb:LabXchange:05007bbf:lx_document:1
- Eau That Smell
  https://www.labxchange.org/library/items/lb:LabXchange:9b81bbc4:lx_document:1

Teacher Preparation:

- BioBuilders Instructor Lab Manuals

Lab Safety Considerations: None

Sequence

Activity Description	*Time*	*Materials*
1. Students create written reports of synthetic biology laboratory investigations	4 days (1 day per lab)	Carolina BioBuilders student lab manuals
2. Student reflection and review of corrected report(s)	1 hr	Internet access

Activity 7: Synthetic biology applications research

Overview: Students research and create a graphic organizer of the various fields in which synthetic biology is applied

Learning Goals: Students will become familiar with the numerous applications of synthetic biology to address current, authentic global issues and problems

Assessed Outcome: Students will share their researched graphic organizers first in small groups and then groups will share out their consolidated graphic organizer of the numerous applications of synthetic biology

Key Vocabulary: antibiotics; vaccines; pharmaceuticals; personalized medicine; gene therapies; food safety; neutraceuticals; GMOs; biodegradable pesticides; nitrogenous fertilizer manufacturing; bioremediation; biofuels; commodity chemicals; biosensors; agricultural feed; bioplastics; biofabrics; biofibers

Materials and LabXchange Pathway(s):

- Synthetic Biology Interactive Timeline
  https://www.labxchange.org/library/items/lb:LabXchange:2b8a3371:lx_simulation:1
- Synthetic Biology on Mars
  https://www.labxchange.org/library/items/lb:LabXchange:ce5310bc:html:1
- Synthetic Biology for Fuels
  https://www.labxchange.org/library/items/lb:LabXchange:30ee7340:html:1
- Toehold Switches for Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:efcfc393:html:1
- Programmable Paper–Advances in Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:8ef549a7:video:1
- Wearable Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:8aa28ef1:video:1
- wFDCF Face Masks
  https://www.labxchange.org/library/items/lb:LabXchange:2e92cd96:html:1
- INSPECTR™: Direct-to-Consumer Molecular Diagnostic
  https://www.labxchange.org/library/items/lb:LabXchange:650b41a2:html:1

Teacher Preparation:

- Why Synthetic Biology is the Field of the Future
  https://www.pbs.org/wgbh/nova/article/why-synthetic-biology-is-the-field-of-the-future/
- Synthetic Biology PD
- *Synthetic Biology–A Primer* by Baldwin et al.

- *BioBuilder–Synthetic Biology in the Lab* by Kuldell et al.
- BioBuilder for Teachers https://biobuilder.org/education/for-teachers/
- Synthetic Biology and the High School Curriculum https://openwetware.org/wiki/Synthetic_Biology_and_the_High_School_Curriculum

Lab Safety Considerations: none

Sequence

Activity Description	*Time*	*Materials*
1. Students research the applications of synthetic biology using provided and independent sources	2 hrs	Current Uses of Synthetic Biology https://archive.bio.org/articles/current-uses-synthetic-biology Synthetic Biology Advances and Applications in the Biotechnology Industry: A Perspective https://doi.org/10.1007/s10295-018-2056-y
2. Students summarize their research in a graphic organizer	1 hr	Internet access
3. Students share and consolidate their graphic organizers in small groups, and then share out their findings with the class	1 hr	Group configurations

Activity 8: Bioethics of synthetic biology

Overview: Students will explore and discuss the bioethics of synthetic biology; students will write a persuasive essay on their point of view that they justify with accurate arguments

Learning Goals: Students will be able to articulate the bioethical issues of synthetic biology and support their point of view

Assessed Outcome: Student essay on the bioethics of synthetic biology will demonstrate their understanding of the issues involved and their ability to support their personal perspective

Key Vocabulary: ethical boundaries; identified risks; human-made genome; public beneficence; responsible stewardship; intellectual freedom and responsibility; democratic deliberation; justice and fairness; biosafety

Materials and LabXchange Pathway(s):

- Bioethics in Gene Editing
  https://www.labxchange.org/library/items/lb:LabXchange:79740f48:html:1

Teacher Preparation:

- Synthetic Biology PD
- The Ethics of Synthetic Biology and Emerging Technologies (Presidential Commission)
  https://www.genome.gov/27542921/the-ethics-of-synthetic-biology-and-emerging-technologies
- Ethical and Philosophical Challenges in Synthetic Biology
  https://researchoutreach.org/articles/machine-metaphors/
- Lab Safety Considerations: Biosafety and Bioethics
  https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7121592/

Sequence

Activity Description	*Time*	*Materials*
1. Students explore the bioethical issues of synthetic biology	2 hrs	The Ethics of Synthetic Biology and Emerging Technologies (Presidential Commission) https://www.genome.gov/27542921/the-ethics-of-synthetic-biology-and-emerging-technologies Ethical and Philosophical Challenges in Synthetic Biology https://researchoutreach.org/articles/machine-metaphors/
2. Students discuss bioethical issues of synthetic biology in small groups; groups share out summaries of their findings	1 hr	Group configurations
3. Students write essays that present the bioethical issues of synthetic biology and they take a position which they can logically justify	1 hr	Internet access

Activity 9: Synthetic biology grant proposal to address an authentic current global issue / problem

Overview: Students working in small groups (2–4 students) select an application of synthetic biology, which can address a current, authentic global issue or problem, use synthetic biology concepts and the engineering design process to create a system of devices composed of parts, create a genetic circuit using logic gates that produces a solution that can be mathematically modeled to address the issue or problem

Learning Goals: Students will apply the knowledge and understanding of synthetic biology concepts and the engineering design process to build (a) device(s) from parts that will create a functional system which can be depicted as a genomic circuit described by a mathematical model

Assessed Outcome: Students will be able to apply synthetic biology to address a current, authentic global issue or problem in a grant proposal that justifies the efficacy of the design and importance of the solution

Key Vocabulary: abstraction; activator; biobricks; bottom-up design; central dogma; chassis; codon optimization; computer aided design CAD; consensus; conserved sequence; constitutive promoter; deterministic model; device; feedback; functional genomics; gene synthesis; genome engineering; graphic user interface GUI; holoenzyme; *in silico, in vitro, in vivo*; inducible promoter; intergenic; inverter; logic gates (AND, OR, NOT, NAND, etc.); model; modularity; next generation sequencing NGS; open reading frame ORF; operator; operon; palindrome; parsimony; part; polymerase chain reaction PCR; primer; promoter; receiver; regulatory region; reporter; repressor; restriction enzyme; ribosome binding site RBS; sender; shotgun sequencing; standardization; genetic switch; synthetic biology; system; terminator; toggle switch; top-down design; additional vocabulary terms depending on student group topics

Materials and LabXchange Pathway(s):

- ABE pathway supportive videos, interactives, texts, etc.
- Introduction to Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:51875b21:video:1
- Synthetic Biology
  https://www.labxchange.org/library/items/lb:LabXchange:773ba7b9:lx_simulation:1
- Cellular Chassis
  https://www.labxchange.org/library/items/lb:LabXchange:a48ca57a:video:1
- Engineering Gene Networks–Integrating Synthetic Biology and Systems Biology
  https://www.labxchange.org/library/items/lb:LabXchange:ac5903c2:video:1

- Synthetic Biology Interactive Timeline https://www.labxchange.org/library/items/lb:LabXchange:2b8a3371:lx_simulation:1
- Introduction to Synthetic Biology and Metabolic Engineering https://www.labxchange.org/library/items/lb:LabXchange:5129aada:video:1
- Abstraction–Teacher slides https://www.labxchange.org/library/items/lb:LabXchange:cf0c7062:lx_document:1

Teacher Preparation:

- Synthetic Biology PD
- *Synthetic Biology–A Primer* by Baldwin et al.
- *BioBuilder–Synthetic Biology in the Lab* by Kuldell et al.
- BioBuilder for Teachers https://biobuilder.org/education/for-teachers/
- Synthetic Biology and the High School Curriculum https://openwetware.org/wiki/Synthetic_Biology_and_the_High_School_Curriculum

Lab Safety Considerations: N/A

Sequence

Activity Description	*Time*	*Materials*
1. Students select a current, authentic global issue that can be addressed with synthetic biology	2 hrs	Internet research
2. Using top-down design, group members brainstorm approaches to solve the problem and reach consensus on the approach	1–2 days	Internet research, discussion
3. Group member research details of the approach to select the system, devices, parts to be used, DNA sequences as well as the chassis to be used	1–2 days	Internet research, discussion, teacher and industry professional mentor feedback
4. Group members create the genetic circuits using logic devices and make predictions based on the model, including quantifying the output and expressing it mathematically	1–2 days	iGEM standardized genetic parts https://igem.org/
5. Group members create synthetic biology design proposal: • Cover Letter to COVID-19 committee • Title Page	2–3 days	Internet access/ word processing

Activity Description	*Time*	*Materials*
• Abstract / Summary • Introduction / Problem Statement • Institutional Background / Resumes • Program Goals and Objectives (Outcomes) • Methods / Implementation Plan • Evaluation Plan • References / Citations		

Activity 10: Synthetic biology grant proposal presentations to panel of industry professionals–Summative assessment

Overview: Student groups submit their grant proposals and make a presentation to a panel of industry professionals

Learning Goals: Synthetic Biology Grant Proposals and presentations are the summative assessment of their understanding and knowledge of synthetic biology and their ability to apply their understanding and knowledge to solve a current, authentic global issue or problem using synthetic biology

Assessed Outcome: The Synthetic Biology Grant Proposal and presentation judged by industry professionals will indicate the degree of understanding and application of synthetic biology

Key Vocabulary: abstraction; activator; biobricks; bottom-up design; central dogma; chassis; codon optimization; computer aided design CAD; consensus; conserved sequence; constitutive promoter; deterministic model; device; feedback; functional genomics; gene synthesis; genome engineering; graphic user interface GUI; holoenzyme; *in silico, in vitro, in vivo*; inducible promoter; intergenic; inverter; logic gates (AND, OR, NOT, NAND, etc.); model; modularity; next generation sequencing NGS; open reading frame ORF; operator; operon; palindrome; parsimony; part; polymerase chain reaction PCR; primer; promoter; receiver; regulatory region; reporter; repressor; restriction enzyme; ribosome binding site RBS; sender; shotgun sequencing; standardization; genetic switch; synthetic biology; system; terminator; toggle switch; top-down design; additional vocabulary terms depending on student group topics

Materials and LabXchange Pathway(s): N/A

Teacher Preparation:

- Synthetic Biology PD
- *Synthetic Biology–A Primer* by Baldwin et al.
- *BioBuilder–Synthetic Biology in the Lab* by Kuldell et al.
- BioBuilder for Teachers https://biobuilder.org/education/for-teachers/
- Synthetic Biology and the High School Curriculum https://openwetware.org/wiki/Synthetic_Biology_and_the_High_School_Curriculum

Lab Safety Considerations: None

Sequence

Activity Description	*Time*	*Materials*
1. Synthetic Biology Grant Proposals and Presentations are given to a panel of industry professionals for judging;	2 hrs	Presentation facility
2. Students review the judging rubric and reflection on their learning and the project experience	1 hr	