BioTechBuilder LAB SKILLS

TOPIC: BUILDING A SOLID FOUNDATION

This topic introduces students to the fundamentals of lab safety and documentation as they work toward independently weighing solid chemicals and responding to chemical spills.

LESSONS (45 minutes each)	
Safety First!	Students are introduced to key safety equipment in the lab through a scavenger hunt that culminates in creation of a map of their lab space.
Handling Hazards	Students learn how to assess and manage hazards posed by chemicals used in the lab and show their understanding through a role playing activity.
Measuring in Metric	Students learn to collect and record accurate measurements with an electronic balance by weighing solids using different metric units.
Keeping a Lab Notebook	Students begin to take ownership of their experiments by creating their first protocol and lab notebook entry as they weigh solid chemicals.
Lab Practical	**Students demonstrate their understanding of lab safety, safe handling of hazardous chemicals, and keeping of a lab notebook.**

Students develop professional practices related to	
Lab Safety	• Identifying and rectifying unsafe lab conditions • Safely measuring, using, and disposing of hazardous chemicals • Safely operating lab equipment such as balances • Identifying and correctly using PPE for a specific task • Safely cleaning up spills from solid hazardous chemicals
Documentation & Following Protocol	• Accurately and legibly labeling reagents • Safely and accurately carrying out the procedures described in a lab protocol / SOP • Recording data accurately and in a timely manner • Maintaining an accurate, up-to-date record of their lab activities
Lab Citizenship	• Conducting lab activities safely and maintain a clean and orderly workspace • Maintaining common lab equipment and materials in clean, well-stocked order • Collaborate and communicate effectively with lab personnel
General Lab Skills	• Select the appropriate equipment and materials for weighing solids • Safely and accurately measure the mass of solid reagents

SAMPLE SLIDES FOR THIS TOPIC

TOPIC: Building a Solid Foundation

Lesson: Measuring in Metric

Lab Activity 20 minutes

Weighing solids

Together with your lab group, you will **weigh solids using different metric units** to become familiar with these units and develop the ability to **estimate** how much solid is needed for a given measurement.

BioTechBuilder LAB SKILLS

TOPIC: MAKING SOLUTIONS

This topic teaches students the math and procedures commonly used to prepare and dilute solutions with units in molarity, %v/v and %w/v. Students prepare single- and multi-solute solutions, measure and adjust pH, and use heat and aseptic technique where needed.

LESSONS (45 minutes each)	
Getting to Know Glassware	Students become familiar with the glassware used to make solutions, as well as how to estimate and read volumes.
Making Stock Solutions	Students practice molarity calculations and prepare a single-solute stock solution.
Diluting Solutions	Students are introduced to serological pipettes and how to prepare serial dilutions.
Micropipetting	Students are introduced to micropipettes and use them to practice transferring liquids.
LAB PRACTICAL I	**Students exchange mystery solutions and use spectrophotometry to prepare a standard curve and measure the mystery solution concentration.**
Making Multi-solute Solutions	Students review solution calculations and prepare solutions with multiple solutes.
Perfecting pH	Students learn how to measure and adjust the pH of a solution.
Saturating Solutions	Students learn how to prepare a saturated solution while practicing %w/v and %v/v calculations and safe operation of a hot plate.
Preventing Bacterial Contamination	Students learn about and practice aseptic technique while pipetting solutions.
LAB PRACTICAL II	**Students rotate to stations where they use a classmate's (anonymized) lab protocol to prepare different solutions.**

Students develop professional practices related to	
Lab Safety	• Safely operating lab equipment such as heating elements

Documentation & Following Protocol	• Visually communicating how their data addresses a hypothesis
Lab Citizenship	• Storing common materials, glassware and reagents appropriately
General Lab Skills	• Selecting appropriate glassware, equipment & materials for solutions • Safely and accurately measuring volumes of liquid reagents (1-1000 ml) • Accurately and reliably preparing single-solute solutions • Safely operating heating equipment, including a hot plate, Bunsen burner • Accurately and reliably preparing solutions (multi-solute, % w/v, %v/v, pH)
Biotechnology Lab Skills	• Accurately measuring and transferring small volumes (0.1 ul - 20 ml) • Use of aseptic technique

SAMPLE SLIDES FOR THIS TOPIC

Agenda

Our plan for today

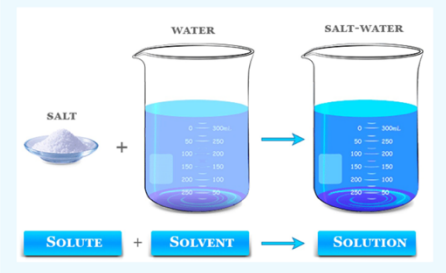
5 min	Introduction	Objectives and pre-lab quiz
5 min	New Ideas	Preparing a solution
15 min	Lab Activity	Prepare blue dye stock solution
10 min	New Ideas	Molarity and dilution calculations
5 min	Wrap-up	Mystery solution concentration

BioTechBuilder LAB SKILLS — Making Stock Solutions

New Ideas

What is a solution?

In today's activity, you will prepare a solution. A solution is created when a solute is dissolved in a solvent.



BioTechBuilder LAB SKILLS — Making Stock Solutions

BioTechBuilder LAB SKILLS

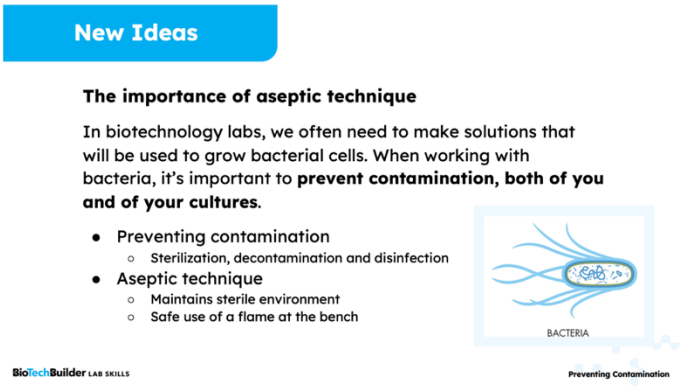
TOPIC: GROWING CELLS

This topic exposes students to culturing bacterial cells on solid and liquid media. In the lab practical, students use spectrophotometry and plating to measure bacterial viability.

LESSONS (45 minutes each)	
Pouring Plates	Students pour agar plates while learning the fundamentals of bacterial cell structure and growth.
Streaking for Single Colonies	Students streak for single colonies from a bacterial slant while learning about selective media.
Culturing a Colony	Students use aseptic technique to prepare liquid selective media and transfer a signal colony into the media for growth overnight.
Measuring Cell Concentration	Students measure OD600 of their overnight culture and prepare a serial dilution of for viability assay plating.
LAB PRACTICAL, part 1	**Students learn how cell concentration and viable cells differ, then count the colonies on their plates to calculate the viability of their bacterial cells. Each student repeats the viability assay experiment for skills assessment.**
LAB PRACTICAL, part 2	**Students repeat the analysis and calculation of the bacterial cell viability using their plates from Lab Practical I, and submit their lab notebook for assessment.**

Students develop professional practices related to	
Biotechnology Lab Skills	• Demonstrating aseptic technique when working with bacterial cultures • Culturing bacteria using solid and liquid media • Isolating bacterial strains using solid or liquid media and quantifying density

SAMPLE SLIDE FOR THIS TOPIC



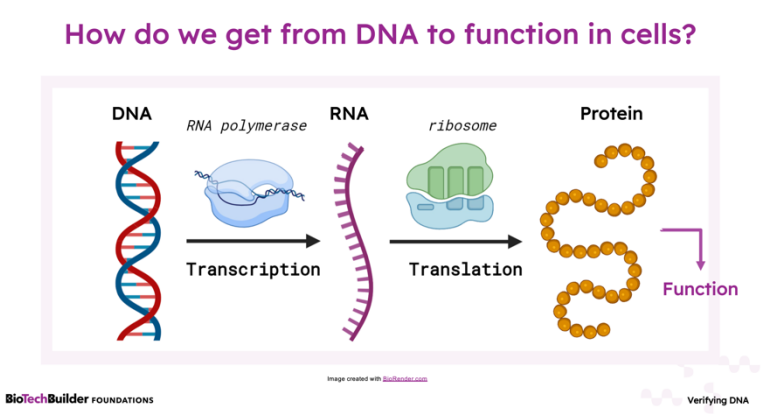
TOPIC: ANALYZING DNA

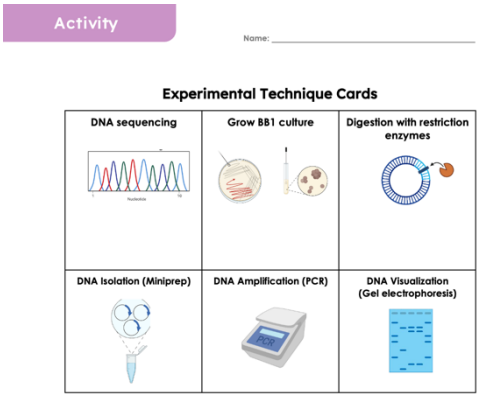
This topic introduces students to DNA techniques used in modern biotechnology. Students begin by growing bacteria in liquid culture, and then they are introduced to DNA analysis techniques including DNA isolation, PCR, restriction digest analysis, gel electrophoresis, and finally sequencing. Other skills covered in this topic include solution preparation and accompanying lab math, micropipette calibration and maintenance, and documentation.

LESSONS (45 minutes each)	
DNA overview	Students streak a transformed *E. coli* strain for single colonies while learning why it is necessary to verify DNA.
Calibrating Pipettes	Students revisit micropipetting and calibrate their instruments to ensure consistent and accurate measurements.
Making Miniprep Solutions	Students prepare plasmid DNA isolation buffers while learning about the process of DNA isolation by miniprep.
Isolating DNA I	Students learn to safely operate a centrifuge as they begin extracting DNA from their bacterial cultures using miniprep protocol.
Isolating DNA II	Students learn how regulatory elements of the bacterial lac operon apply to the plasmid they are isolating.
Amplifying DNA I	Students learn how the polymerase chain reaction can be used to amplify and verify DNA segments, illustrating their understanding by writing their own PCR protocol using manufacturer's guidelines.
Amplifying DNA II	Students use their own PCR protocol to amplify the DNA they isolated from their bacterial cultures.
QUIZ I	**Students design primers, calculate reagent volumes, and predict the length of a PCR product**
Digesting DNA	Students learn about restriction enzymes and apply their understanding to verify and analyze their PCR products.
Visualizing DNA I	Students pour gels for electrophoresis of their digested PCR DNA.
Visualizing DNA II	Students practice loading gels.
Visualizing DNA III	Students analyze their PCR DNA by gel electrophoresis.

QUIZ II	Students select enzymes, calculate the length of the DNA digestion products, and predict the results of agarose electrophoresis
LAB PRACTICAL I	Students demonstrate gel electrophoresis competency by pouring, loading, running, and analyzing agarose gel.
Sequencing DNA	Students learn how DNA sequencing works and how to read and interpret DNA sequencing results of their plasmid DNA.
QUIZ III	Students demonstrate their knowledge of techniques used to verify DNA by answering fundamental and situational questions.
LAB PRACTICAL II	Students use different DNA verification techniques to solve a forensic mystery.

Students develop professional practices related to	
Documentation & Following Protocol	• Creation and use of a protocol • Recording and analysis of data • Keeping a lab notebook
General Lab Skills	• Selecting the appropriate equipment and materials for weighing solids • Safely and accurately measuring the mass of solid reagents • Accurately and reliably preparing solutions
Biotechnology Lab Skills	• Use of aseptic technique and culturing bacteria • Performance of DNA-oriented lab techniques and assays (DNA isolation, PCR, restriction digest analysis, gel electrophoresis) • Navigating sequence alignment tools
Biomanufacturing Skills	• Verifying the calibration of single channel micropipettes • Identifying, creating, and using SOPs





TOPIC: ANALYZING PROTEINS

This topic teaches students to express and analyze a protein of interest using molecular techniques. Hands-on experiments unify and apply content related to gene expression, protein induction, enzyme activity, protein concentration measurements, and separation techniques including column chromatography and SDS-PAGE.

LESSONS (45 minutes each)	
Protein Overview	Students review central dogma, inducible gene expression (lac operon), and then passage an engineered bacterial strain by restreaking for single colonies.
Bacterial Growth Curves	Students learn about bacterial growth curves, and then aseptically inoculate a bacterial colony from solid to liquid media.
Protein Induction	Students learn how a chemical can induce bio-production of an enzyme, and then initiate the overproduction of an enzyme in the bacterial strain they have grown.
Cell Viability I	Students use spectrophotometry and serial dilution to evaluate the impact of induction on the growth and viability of their induced bacterial strain.
Cell Viability II	Students assess the cell growth data, calculate viability, and analyze the impact of enzyme overproduction on cellular fitness.
Lab Practical I Part 1	**Students repeat the viability assay to assess the impact of cold storage on the induced bacterial strain.**
Lab Practical I Part 2	**Students analyze the viability assay plates and summarize the impact of cold storage on induced bacterial strain, then learn about enzymes as catalysts.**
Solution Preparation	Students follow an SOP to prepare reagents necessary for enzyme activity measurement.
Enzyme Activity Measurement	Students learn how colorimetric enzyme assays work, and then measure enzyme activity in their uninduced and induced bacterial cells to calculate enzyme activity.
QUIZ I	**Students are evaluated on their understanding of cell growth, induction, viability, activity calculation**
Standard Curve	Students learn about the linear relationship between concentration and absorbance, and then serially dilute a known protein to prepare a standard curve.
Calculating Protein Concentration	Students plot absorbance vs concentration and use that standard curve to determine the protein concentration in their induced bacterial cells.

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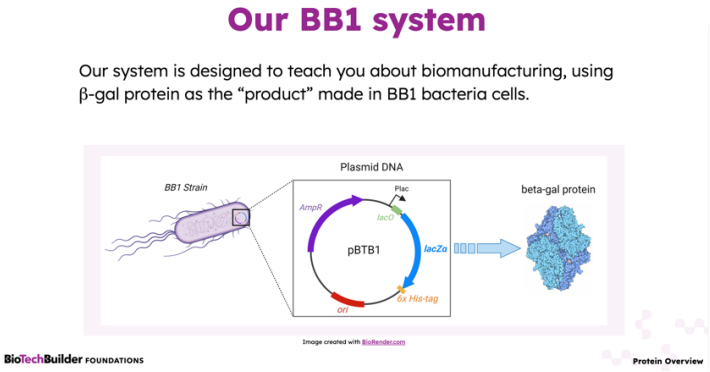
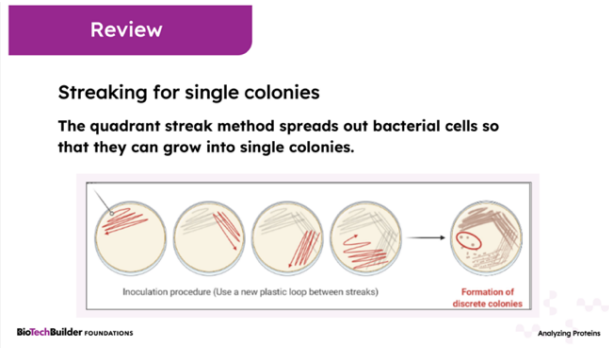
Protein Purification I	Students survey numerous techniques for disrupting cells, then use chemicals to prepare protein lysates from induced cells.
Protein Purification II	Students survey numerous protein separation techniques, then use affinity chromatography to purify the overproduced enzyme.
Visualizing Protein I	Students learn how denaturing gel electrophoresis separates proteins by size, then load select fractions from their protein purification onto SDS-PAGE.
Visualizing Protein II	Students learn how proteins are visualized and how their size is determined, then document predictions for their experiment and use Coomassie to stain the gel.
Visualizing Protein III	Students will compare their documented predictions of the gel to their data, then review the various protein analysis techniques they explored in the lessons.
QUIZ II	**Students demonstrate their knowledge of spectrophotometry, cell lysate preparation techniques, and protein gel electrophoresis**
LAB PRACTICAL II	**Students will be assessed on their ability to generate a standard curve and use that curve to measure the concentration of an unknown solution**

Students develop professional practices related to	
Biotechnology Lab Skills	• Use of aseptic technique and culture bacteria • Measurement of concentration using spectrophotometry • Performance of protein-oriented lab techniques and assays (chemical induction, protein concentration, and activity measurement) • Performance of protein separation techniques (SDS-PAGE and chromatography)

SAMPLE SLIDES FOR THIS TOPIC





BioTechBuilder APPLICATIONS

TOPIC: BIOMANUFACTURING

This topic explores the life cycle for production and manufacturing of bioproducts, including upstream processing, downstream processing, and quality control. The labs include scale-up processes, viability assays, and product activity tests while students document every step using batch records. The importance of Good Manufacturing Practice (GMP) is emphasized through research on pre-GMP case study examples.

LESSONS (45 minutes each)	
Biomanufacturing Overview	Students are introduced to biomanufacturing, and then investigate commercially available bioproducts and discuss their benefits and importance in the current market.
Fermentation I	Students learn about the stepwise process for growing large cell volumes, and then expand a cell stock into a 10 ml culture.
Fermentation II	Students use an online simulation to compare microbial and mammalian cell expansion processes, then measure cell concentration and viability in their 10 ml culture, recording data using a Batch Record form.
Fermentation III	Students calculate the number and percentage of viable cells, then seed a 100 ml culture with a known number of viable cells.
Fermentation IV	Students evaluate the 100 mL culture using the same method used for evaluating 10 mL culture. Through an online simulation, students learn hemocytometer-based cell counting.
QUIZ I	**Students calculate cell concentration and viability from microbial and mammalian cell sample data provided by the instructor.**
LAB PRACTICAL I	**Students measure OD600 and perform viability assay on growing bacterial cells.**
Measuring Bioproduct I	Students induce engineered *E. coli* to produce the bioproduct (β-galactosidase) and learn about Quality Control and Batch Record.
Measuring Bioproduct II	Students follow SOP to make solutions for an enzyme activity assay and record their process on a Batch Record form.
Measuring Bioproduct III	Students measure the enzymatic activity of the bioproduct to ensure the scaled-up *E. coli* cells are behaving as expected.
Industrial-Scale Fermentation I	Students use an online simulation of a 2000 liter bioreactor and research pre-GMP case study examples.

Industrial-Scale Fermentation II	Students develop an SOP as an in-class activity then present their research on pre-GMP and discuss the importance of GMP.
QUIZ II	**Students demonstrate their knowledge and understanding of GMP regulation**
LAB PRACTICAL II	**Find the errors in Batch Record, lab setup, and calculation**
Downstream Processing I	Students consider the consequences of extracellular vs intracellular localization of products, and simulate harvesting techniques based on this property.
Downstream Processing II	Students learn about chemical, mechanical, and temperature-dependent cell disruption techniques and carryout procedures to release lysozyme from chicken eggs.
Downstream Processing III	Students examine the properties of lysozyme, learn about industrial scale downstream processes, including product formulation and packaging methods. In the lab, students test egg lysozyme purified under different conditions.
Downstream Processing IV	Students are introduced to protein purification methods that rely on physical characteristics of the bioproduct, then analyze the data from their lysozyme purification experiment, concluding with an exercise to illustrate the need of well designed clean rooms for safe manufacturing of bioproducts.
QUIZ III	Students are asked about downstream processing from lysate preparation to purification from contaminants to concentration and packaging a bioproduct
LAB PRACTICAL III	**Trace the production of a novel product and troubleshoot errors in workflow**

Students develop professional practices related to	
Biomanufacturing	• Explain the life cycle of a bioproduct starting with scaling-up growth, fermentation, purification, and product packaging while monitoring for quality control throughout the process • Creation and following of SOPs • Accurate documentation using batch records • Importance of executing procedures in compliance to GMP regulations

BioTechBuilder APPLICATIONS

TOPIC: SYNTHETIC BIOLOGY

This topic allows students to explore each stage of the engineering "Design-Build-Test-Learn" (DBTL) cycle, first using existing BioBuilder kits and then through the application of BioBuilder's abstraction hierarchy to design a novel biotechnology of their own. Lab skills focus on microbial culturing, transformation of both bacteria and yeast, and measurement of cellular outputs.

LESSONS (45 minutes each)	
Synthetic Biology Overview	Students are introduced to the Design-Build-Test-Learn cycle and an abstraction hierarchy for designing novel biotechnologies, then grow two bioengineered bacterial strains on solid media.
Design Cycle I	Students consider the design process that invented a banana-smelling bacteria, then start liquid overnight cultures of that strain.
Design Cycle II	Students examine the genetic elements that were engineered to control banana-scent production, and then grow the bioengineered cells to different growth stages.
Design Cycle III	Students discuss qualitative and quantitative data, build a data table, and collect growth and scent data from the cells they have grown.
QUIZ I	**Students apply the design process to specify a plastic eating bacteria and design a data table for a preliminary experiment testing its function.**
Build Cycle I	Students consider the design process that invented a color-generating bacteria, then patch two untransformed strains on solid media.
Build Cycle II	Students explore the concept of cellular chassis, then prepare solutions for bacterial transformation.
Build Cycle III	Students discuss positive and negative controls, then transform two plasmids into two host strains, documenting their predictions for the experimental results.
Build Cycle IV	Students analyze transformation data, document discrepancies from predictions, develop protocol variation to improve results, and repatch cells for lab practical.
LAB PRACTICAL I	**Students repeat transformation using 4-2 under different experimental conditions**
Test Cycle I	Students compare bottom-up and top-down design processes, then grow four bioengineered bacterial strains on solid media.

Test Cycle II	Students use bioinformatics to consider how sequence variations can impact function, and follow SOP to prepare solutions for enzyme activity measurement.
Test Cycle III	Students are introduced to standardization of DNA parts, and measure the enzyme activity in four bioengineered bacterial strains.
QUIZ II	Students analyze the protocol and data for 10 strains that are variations of the four tested.
Test Cycle IV	Students learn basic statistical analysis of data, and grow triplicate overnight for one bioproduction strain
LAB PRACTICAL II	**Triplicate measurements of enzyme activity, calculation, analysis**
Redesign I	Students consider the engineering approach to reliable performance, then pour YPD petri dishes.
Redesign II	Students look at yeast as a model organism, and then streak yeast cells for single colonies.
Redesign III	Students learn about yeast that have been re-engineered to produce Vitamin A, then streak Vita Yeast strains for single colonies.
LAB PRACTICAL III	**Students develop a PCR protocol for a new gene of interest, and predict the size of the PCR product.**
Redesign IV	Students explore the concept of codon shuffling, then transform a white colony with a codon shuffled copy of a gene on a plasmid and select for transformants.
QUIZ III	**Students illustrate their understanding of genetic complementation and positive and negative controls by predicting the outcome of the yeast transformation they performed.**
Biodesign I (no lab)	Students analyze their yeast transformation data, then design a PowerPoint slide to illustrate their understanding of the experimental system.
Biodesign II (no lab)	Students work in groups on BioBistro and TechTokens activities.
Biodesign III (no lab)	Students watch part of Idea Accelerator Video III and brainstorm biotechnology ideas for various topics (Food/Energy, Environment, Health/Medicine, and other novel ideas)
Biodesign IV (no lab)	Students watch video of Cambridge City Council hearings in 1976, and work through questions on pg 84-89 in BioBuilder book
FINAL PROJECT	**Students present design idea, ethical analysis of existing project, or data from lab.**

BioTechBuilder APPLICATIONS

Students develop professional practices related to	
Biotechnology Lab Skills	• Use of aseptic technique and culturing of bacteria and yeast • Statistical analysis of replicate samples • Bacteria and yeast transformation • Use of complementation in yeast transformation • Measurement of concentration and enzyme activity using spectrophotometry • Documentation of results • Written and oral data communication

SAMPLE SLIDES FOR THIS TOPIC