CURRICULUM DESIGN GUIDE

Designing and implementing engaging activities for all.

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Introduction

Curriculum design is a multi-step process that involves creating, testing, evaluating, and revising lesson plans and educational materials. The purpose of this curriculum guide is to illustrate Team Saptasense's approach to the design process. We begin with an overview of our pedagogical approach and general activity design framework. Then, we discuss how one of our activities was drafted and revised to ultimately produce an accessible and engaging experience for our students.

Pedagogical Theory

Identifying pedagogical goals prior to activity design can help make activities more effective and engaging. For example, Saptasense's overarching goals were to:

1. Create engaging activities to teach diverse audiences about synthetic biology.
2. Thoughtfully implement lesson plans to promote mutual learning and maintain an open dialogue.
3. Use a learner-centered education style to maximize student engagement.
4. Design accessible and adaptable materials that are conducive to all learning styles and abilities.

Three common pedagogical approaches and tools for developing and evaluating educational materials are Student-Centered Instruction, Universal Design for Learning, and Bloom's Taxonomy, and are briefly discussed below.

Student-Centered Instruction (SCI)

One way to encourage an open dialogue is through inquiry-based learning and student-centered instruction (SCI). Traditional approaches to education often place the responsibility on the teacher. Because students do not feel responsible for their own learning, they tend to be less engaged and inquisitive about the material. Conversely, SCI empowers students with the ability to take charge of their own education. Placing students in the center of the learning process has been suggested to improve motivation, understanding, and knowledge retention.[1] One way to defer the instructional responsibility from teachers to learners is by promoting active learning over conventional lecture-based instruction. Active learning is a method of keeping students mentally – and sometimes even physically – involved in the learning process through activities that promote critical thinking and problem solving. Studies suggest

[1] Michael, Joel. "Where's the evidence that active learning works?." Advances in physiology education (2006).

that active student-led learning creates a more autonomous environment and subsequently improves student engagement compared to instructor-led learning.[2]

Universal Design for Learning (UDL)

The Universal Design for Learning (UDL) model promotes a more inclusive learning environment by accommodating the needs and abilities of all students. UDL works to eliminate unnecessary hurdles that certain people – such as those with disabilities – may face in traditional learning environments.[3]

Bloom's Taxonomy

A pedagogical framework used to promote higher order thinking is Bloom's Taxonomy. The Bloom's taxonomy model describes six hierarchical levels of cognitive function: Remember, Understand, Apply, Analyze, Evaluate, Create. This framework is illustrated in Figure 1.

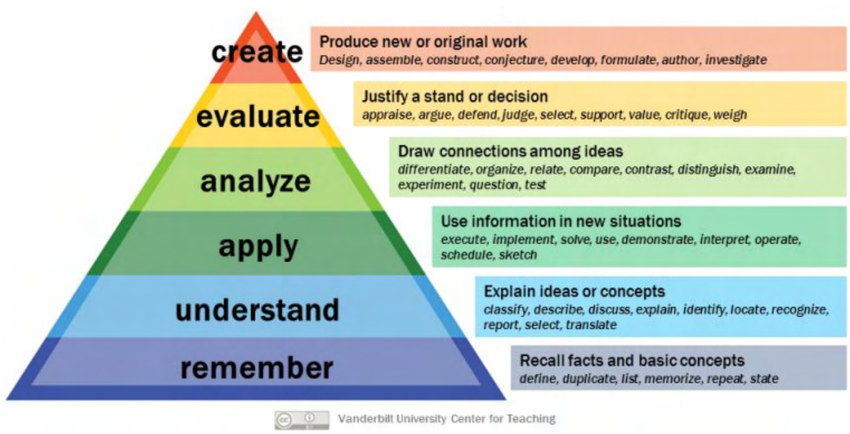


Figure 1. Bloom's Taxonomy: Bloom's Taxonomy describes six levels of cognitive function: remember, understand, apply, analyze, evaluate, and create. Source: Armstrong, P. (2010). Bloom's Taxonomy. Vanderbilt University Center for Teaching. Retrieved 3 October 2022 from https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/.

[2] Bernot, Melody J., and Jennifer Metzler. "A comparative study of instructor-and student-led learning in a large nonmajors biology course: Student performance and perceptions." Journal of College Science Teaching 44.1 (2014): 48-55.

[3] Rose, David H., and Anne Meyer. A practical reader in universal design for learning. Harvard Education Press. 8 Story Street First Floor, Cambridge, MA 02138, 2006.

Implementing Engaging Activities

While pedagogical theories provide a useful framework for activity design, implementing activities in the classroom requires separate skills including strong interpersonal skills and adaptability. Importantly, maintaining an open dialogue and encouraging mutual communication between students and instructors can help promote student engagement and higher-order thinking.

Characteristics such as age and prior knowledge can influence which instructional methods are best suited for each audience. For example, younger students tend to respond better to kinesthetic activities in which they are physically engaged with the content. Older audiences may require a more diverse instructional style that integrates auditory, visual, and kinesthetic activities. In general, activities that require students to ask questions and make observations – such as experiments or cut-and-paste activities – promote open dialogue to a greater extent than activities that involve passive learning such as instructor-focused lectures.

When leading educational activities, it can be helpful to work with smaller groups of students at a time. This allows students who are otherwise uncomfortable asking or answering questions in a larger group to connect better with the instructor. Because prior knowledge can vary greatly in an audience, using an individualized approach rather than constant whole-class instruction can foster more meaningful relationships between students and instructors, thereby promoting a more open dialogue.

Activity Design Framework

Using the pedagogical theories described previously, Team Saptasense developed a novel activity design framework to better fit the needs of our audiences. First, we identified five main criteria that are important to consider when developing activities (represented as larger rectangles). Then, we further fractionated each section using characteristics of Bloom's Taxonomy, Student-Centered Instruction, and Universal Design for Learning. This framework is illustrated in Figure 2.

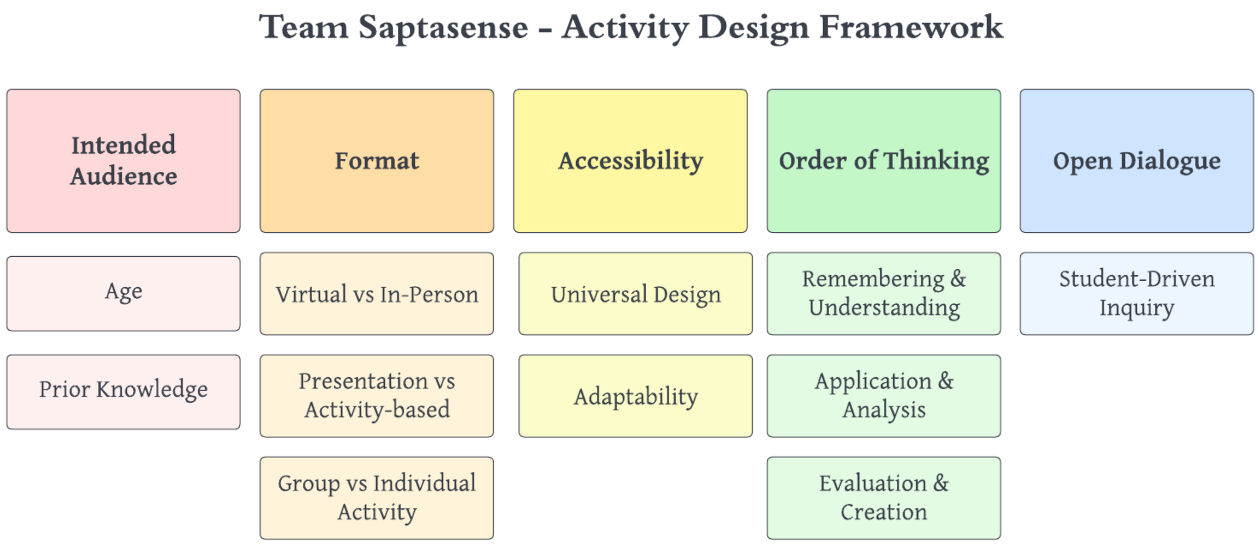


Figure 2. Activity Design Framework: Team Saptasense developed a general pedagogical framework to design engaging, accessible, and student-centered lesson plans for each educational initiative. Our primary considerations for activity design were: intended audience, format, accessibility, order of thinking, and open dialogue.

Though each educational initiative varies in terms of audience and format, Saptasense's Activity Design Framework can be used to thoughtfully design engaging and student-specific lesson plans. The application of this framework is demonstrated in the next section using one of Team Saptasense's synthetic biology activities: Bacteria Superheroes.

Case Study: Bacteria Superheroes

The purpose of this section is to demonstrate how the Activity Design Framework can be used to develop and revise engaging and inquiry-based activities. A sample Saptasense activity, Bacteria Superheroes, will be used to describe the design, revision, and implementation process in four phases: (1) Brainstorming & Drafting, (2) Version 1, (3) Version 2, and (4) Version 3.

Note: *There are many different ways to apply the pedagogical framework to curriculum design. This is simply one example!*

Brainstorming & Drafting

Before creating or implementing an activity, it is important to first outline the specific goals and learning objectives for the lesson. Team Saptasense wanted to develop a synthetic biology activity that would teach students about genetic engineering and its diverse applications. After discussing potential materials such as a bacteria coloring sheet and a presentation about the genetic engineering process, we decided to design a more engaging cut-and-paste worksheet instead.

Our team's overall goal was to illustrate what synthetic biology is and how bacteria can be genetically engineered to solve problems. Using our pedagogical knowledge and activity design framework, we developed the following goals and learning objectives, ensuring that they were measurable and actionable. For this version of our activity, our audience age ranged from 9-11 years old.

<u>Lesson Goals (v0)</u>

1. Facilitate discussion about genetically-modified organisms and their real-world applications.
2. Illustrate the main steps of bacterial cloning, including restriction enzyme digestion and transformation.
3. Encourage students to develop novel solutions to particular problems of their choosing.

<u>Learning Objectives (v0):</u>

- Explain the diverse applications of genetic engineering and genetically-modified organisms.
- Engineer a synthetic biology-based solution to a scientific problem.
- Describe how bacteria can be used as biological tools.

After outlining the goals and objectives for the activity, our team sketched out our idea for the worksheet (illustrated in Figure 3).

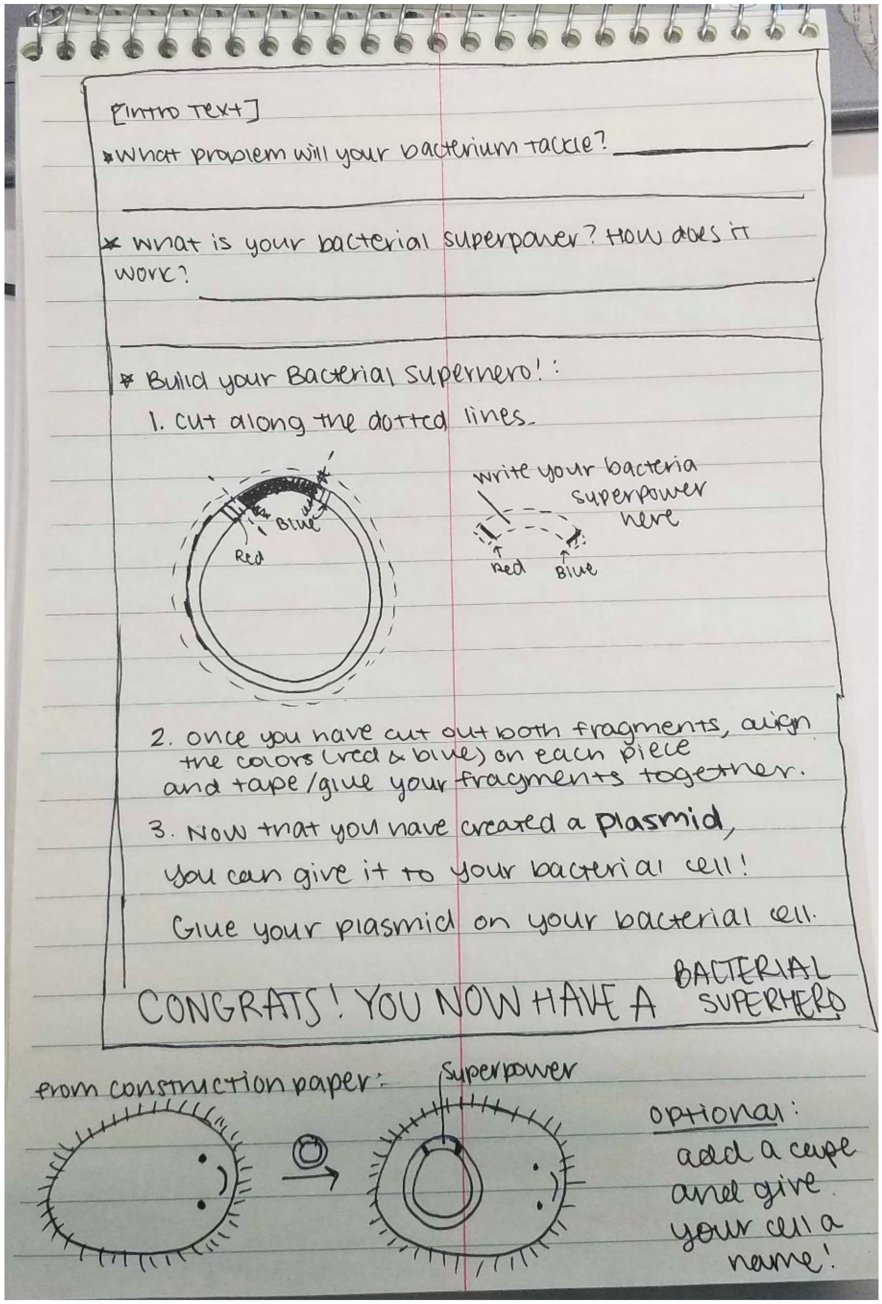


Figure 3. Bacteria Superheroes v0 Sketch: Version 0 of Saptasense's "Bacteria Superheroes" activity.

To illustrate scientific terms in a way that is accessible (and fun!) for younger students, we drew an analogy between engineered bacteria and superheroes. Specifically, when a particular gene, or "superpower", is inserted into a bacterium, the bacterium gains a new ability and becomes a "superhero."

In addition, we included a step that prompted students to cut and paste their "superpower" gene of interest into a vector. Specifically, students would be asked to cut at specific locations on the vector backbone and match the colors (red and blue) to the colors present on their gene fragment. Finally, students would "transform" their plasmids into their bacterium by taping it onto a bacterial cell illustration. At this stage of the design process, we had successfully identified our learning objectives, outlined worksheet questions, and drafted the flow of the lesson.

Version 1

Next, we used our activity outline to create the first version of our Bacteria Superheroes worksheet (Figure 4).

As we were designing the cut-and-paste plasmid portion between the initial outline and Version 1 of the activity, we realized that the initial color-matching idea could be improved. Specifically, asking students to match red and blue lines together would not be accessible to those that are color blind. Instead, we decided to use different shapes as "restriction sites" that students could match up on their superpowers and plasmids. While we could have used letters (i.e., DNA nucleotides) in place of the colors, we felt that shapes would allow all students to engage with the material without having to fully grasp the concept of DNA and restriction enzymes.

This allowed students to engage with the material without having to fully grasp the concept of DNA and restriction enzymes. As we developed our worksheet, we frequently referenced the Activity Design Framework. Specifically, we outlined if and how our activity addresses the five pillars of the framework:

- Intended Audience: Ages 9-11, varying levels of prior knowledge.
- Format: In-person, activity based, individual activity.
- Accessibility: Worksheet is adaptable. Though the cut-and-paste portion may be difficult for some students, this problem can be addressed by providing pre-cut paper strips.
- Order of Thinking: Worksheet focuses on application and creation based questions. After briefly learning about bacteria, DNA, and genes, students must apply their knowledge to choose a problem and design a novel solution.
- Open Dialogue: Instructors will aim to maintain open dialogue by providing many opportunities for students to ask questions, both in large and small groups.

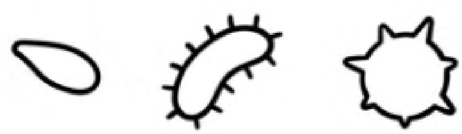
Bacteria Superheroes

What problem will your bacteria tackle?

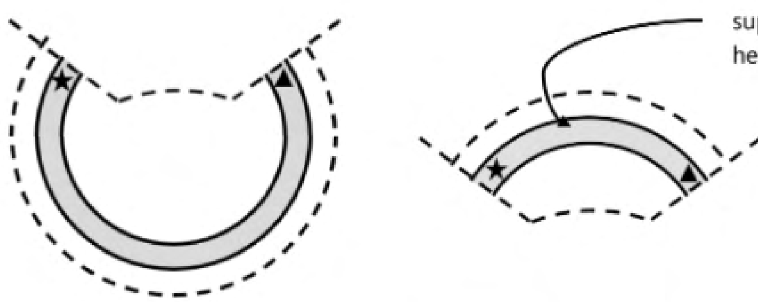
What is your bacterial superpower? How does it work?

Build your bacterial superhero!

1. Draw your bacteria on a piece of construction paper. Make sure to make it big! Bacteria can take many different forms! Use the photos below for inspiration, or draw your own!



2. Cut along the dotted lines:



3. Once you have cut out both fragments, align the matching shapes on each piece and tape or glue the fragments together.
4. Now you have created a plasmid, and can give it to your bacterial cell! Tape or glue your plasmid in your bacteria.
5. Add a cape and give your cell a name!

Congrats! You have a bacterial superhero

Figure 4. Bacteria Superheroes v1 Worksheet: Version 1 of Saptasense's "Bacteria Superheroes" activity (ages 9-11).

We tested Version 1 of our Bacteria Superheroes activity during a week-long camp at a local science center in Rochester, NY. Overall, we felt that the activity kept students engaged and interested in the material.

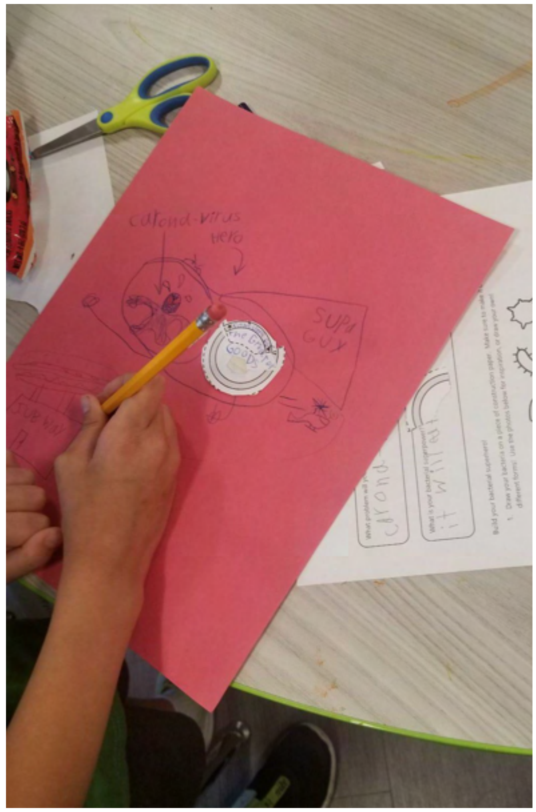


Figure 5. Student Completes Bacteria Superheroes Activity: A student illustrates their Bacterial Superhero (which they named "Coronavirus Hero" which has been engineered to defeat COVID-19.

However, we noticed that some students struggled to physically cut out their plasmids as it required strong fine motor skills and high attention to detail. In addition, some students finished the activity faster than others due to differences in prior knowledge. Because this version of the activity only included two "restriction site" shapes, it was not challenging enough for the older students. Consequently, our team decided to revise and design a new version of the Bacteria Superheroes activity that would be more engaging for older students.

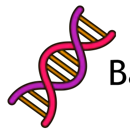
Version 2

In the next version of our Bacteria Superheroes activity, we focused on promoting higher-order thinking skills and providing more "real world context" in a way that would be more suitable for students with more prior knowledge. Originally, students were asked to both identify a problem and design a solution. Though this allowed them to be more creative, it also was frustrating for students who could not think of a creative solution (who therefore became unmotivated). In Version 2, we decided to provide students with a gene of known function and asked them to identify a potential use for the gene. This way, we were able to encourage higher order thinking while providing a little more structure to the activity.

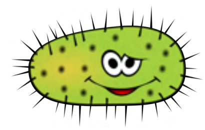
In addition, we made the cut-and-paste portion of the activity more challenging by adding in additional "restriction site" shapes. As a result, students had to use higher-order thinking skills to analyze and determine how the vector and gene could fit together to form a functional plasmid. Finally, we removed the illustrations of different bacterial shapes to foster more creativity during the design process. The resulting Version 2 of the activity is illustrated in Figure 5.

During this process, we revisited our Activity Design Framework and evaluated our activity using the five pillars of the framework:

- Intended Audience: Ages 12-15, varying levels of prior knowledge. Assume some, but not comprehensive, knowledge of DNA and bacteria.
- Format: In-person, activity based, individual activity.
- Accessibility: Worksheet is adaptable. Though the cut-and-paste portion may be difficult for some students, this problem can be addressed by providing pre-cut paper strips.
- Order of Thinking: Worksheet focuses on application, evaluation, and creation based questions. After briefly learning about bacteria, DNA, and genes, students must apply their knowledge to determine what purpose a particular gene could serve.
- Open Dialogue: Instructors will aim to maintain open dialogue by providing many opportunities for students to ask questions, both in large and small groups.



Bacterial Superheroes



Did you know that scientists can engineer bacteria to solve real-world problems? Today, you will have the opportunity to design a "bacterial superhero" yourself!

Instructions:

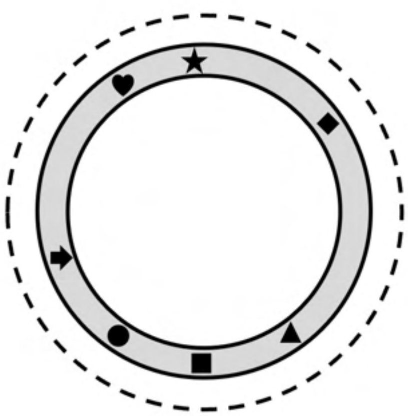
1. The INS gene encodes insulin, a protein that is important for metabolic pathways including glucose uptake. **Based on this information and your prior knowledge, what is one way this gene might be used to solve a real-world problem?**

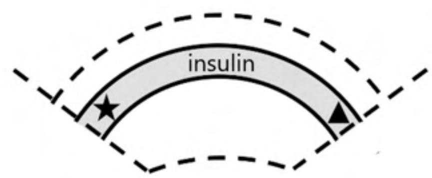
   ____

   ____

2. In order to engineer your bacteria to produce insulin, you must first assemble a **plasmid**. Scientists use **restriction enzymes** which act like scissors! Restriction enzymes cut at specific spots in DNA, known as **restriction sites**.

   a. To begin, cut out the gene fragment and plasmid below:

   b. Now, arrange the pieces to make two shapes on your gene align with two identical shapes on your plasmid.

   Which shapes align? _____ & _____. These are your **restriction sites**.

   c. Use scissors to cut your fragments **only** where the two fragments align. (Just like a restriction enzyme would!)

   d. Finally, tape the insulin gene fragment and plasmid together. You have successfully assembled a recombinant **plasmid**!!

3. ONE FINAL STEP: **TRANSFORMATION!** On a separate piece of paper, draw a bacterial cell. Then, tape your plasmid onto your bacterium.

Figure 5. Bacteria Superheroes v2 Worksheet: Version 2 of Saptasense's "Bacteria Superheroes" activity (ages 12-15).

Though Version 2 provided more opportunities for higher-order thinking through things like restriction site matching, we felt that it was not as suitable as it could have been for all learning styles. While worksheets provide a useful way to organize information and test student knowledge, they are not as physically engaging as kinesthetically-focused activities. In our third and final iteration of the Bacteria Superheroes activity, we transformed our 2D activity into a 3D one.

Version 3

For Version 3 of the Bacteria Superheroes activity, we replaced the worksheet with a more hands-on activity. Instead of paper cutouts, we decided to use pipe cleaners as "plasmid" pieces. In past versions of the activity, the worksheet limited the amount of open discussion that could occur between learners and educators. By reducing the instructional rigidity, our activity became more student-centered and promoted physically and mentally active learning.

Like in previous versions, students were asked to pick a problem they want to solve with genetic engineering and design a "superpower" in response. However, in Version 3, students were asked to choose two pipe cleaner fragments: one large piece representing the plasmid backbone and one small piece representing the gene insert (Figure 6).

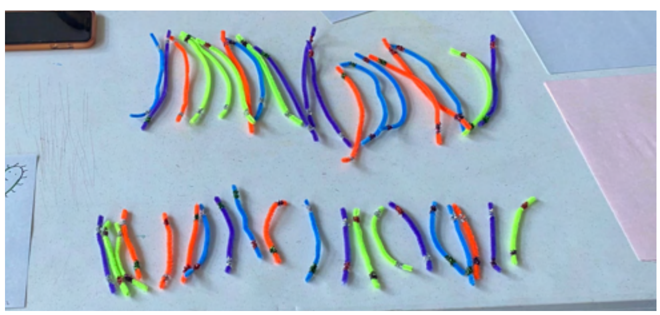


Figure 6. Bacteria Superheroes v3 Materials:
Pipe cleaners used as part of Version 3 of the Bacteria Superheroes activity (ages 8-14).

To add an additional layer of critical thinking, each plasmid was marked with a different colored and textured fragment on either side to represent restriction sites. Once students picked two pieces that matched, they were told to write their superpower on a piece of paper and thread it through the pipe cleaner. Next, students physically joined the gene insert and plasmid backbone by twisting the pipe cleaners together. They taped their engineered plasmid onto their papers, representing "transformation."

Again, we used our Activity Design Framework as we revised and implemented our Version 3 materials:

- Intended Audience: Mostly ages 8-14, potentially as young as 4 years old., very diverse levels of prior knowledge.
- Format: In-person, activity based, individual activity with some collaboration.
- Accessibility: Does not require using scissors. Twisting the pipe cleaners may be difficult for some students, but activity can be adapted to skip this step.
- Order of Thinking: Students must continuously apply their knowledge to create and evaluate their project. Critical thinking is promoted through conversation with instructors.
- Open Dialogue: Instructors will maintain a constant open dialogue with students by eliminating highly-structured prompts and answering student questions.

Figure 6. Bacteria Superheroes v3 Activity: Top Left: A child draws a bacterium on their paper. Top right: A child inserts a pipe cleaner through a small piece of paper that has a "superpower" written on it. Bottom left: Collection of "superpowers" that students gave their Bacteria Superheroes. Bottom right: An example Bacterial Superhero that has been designed to "teleport".

Unlike in Versions 1 and 2, we were able to individualize each portion of the activity. As students completed the activity, they asked questions ranging from “Aren’t bacteria germs though?” to “Can you tell me more about how genetic engineering is actually used in the lab.” Without a worksheet, students were able to think more critically and creatively about how they wanted to design their plasmids. Due to the versatility of our materials, we were able to adapt the activity to each student’s age, prior knowledge, and abilities.

Conclusion

Designing effective and engaging educational materials is a cyclical process that requires educators to critically design, implement, evaluate, and revise their materials. In this guide, we have demonstrated how pedagogical approaches such as Student-Centered Learning, Universal Design for Learning, and Bloom’s taxonomy can be used to guide the curriculum design process. We have discussed the framework for and implementation of a sample activity designed by Team Saptasense. Though there is not one “correct” approach to teaching and learning, we hope that this curriculum design guide will help create engaging, accessible, and inquiry-based educational experiences for all students.