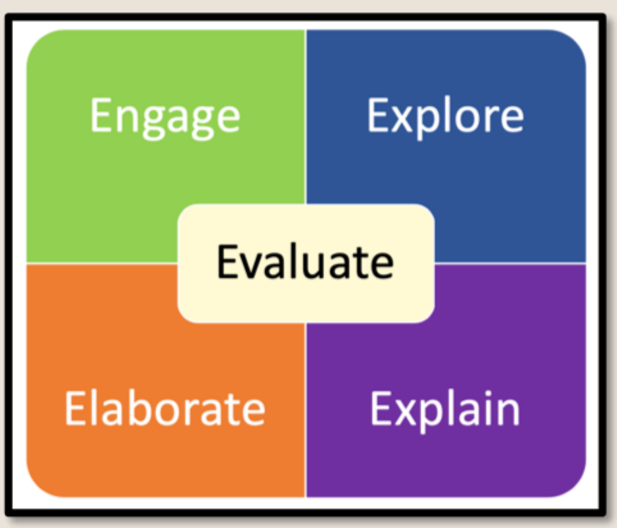
STEM Instructional Planning Guide

Audience: Educators

Tool Overview: This instructional planning guide provides educators with best practices for developing STEM curricular units, lessons, and activities. This guide is designed to help facilitate the curriculum development process. The structure embedded within this guide promotes the development of student knowledge and skills through engagement in an inquiry-based integrated unit that culminates with an engineering design challenge. The provided templates are meant to be used as an example and can be adapted to meet the needs and abilities of students.

The unit plan template scaffolds activities to help students build background knowledge in order to be able to apply and make informed design decisions. Students will engage in an exploration of content through multi-disciplinary activities and then use the Engineering Design Process to design solutions to a problem.

The **5E Learning Cycle Framework** (Bybee, 2006) originally adapted from Atkin's and Karplus' instructional model of guided discovery. The learning cycle is a widely accepted model for planning inquiry instruction. Research indicates that instruction using the learning cycle model results in the development of reasoning skills, an increased interest in content, and an increased achievement in the learning of the content, especially science. The learning cycle is designed to allow students an opportunity to surface and examine their prior conceptions. Once ideas are revealed, students have an opportunity to explore ideas, arguing about and testing them in the process.



Engage: is designed to interest students in the concept and to provide opportunities for making connections to past and present learning.

Explore: provides the opportunity for students to become directly involved with the key concepts of the lesson through guided exploration that requires them to probe, inquire, and discover. The exploration stage provides students with a set of common experiences and social interactions as they begin making sense of the new concept.

Explain: the instructor, acting in a facilitation role, uses this phase to offer further explanations and provide additional meaning or information, such as correct terminology. Students communicate conceptual understandings by making evidence-based claims as they share what they have learned using accurate and appropriate terminology.

Elaborate: allows students to apply, extend, and expand their understanding of the processes and concepts of the lesson to real-world situations.

Evaluate: both the teacher and the student check for understanding of the learning goal of the lesson. Assessment is on-going throughout the unit and promotes the use of both formative and summative assessments.

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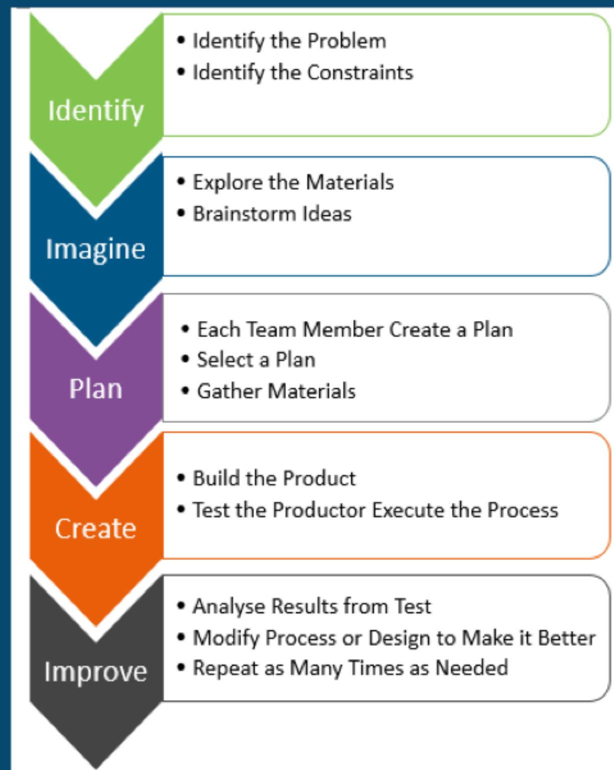
The **Engineering Design Process** is an instructional method that can be used to teach and apply a variety of concepts in an integrated fashion. Students engage with integrated concepts from multiple disciplines and utilize design thinking as a mechanism to design a solution to an authentic problem. There are multiple model variations of the engineering design process, however they all share the basic practices of asking questions or defining problems, brainstorming, planning a design, creating and testing a design, and improving the design. Throughout the process students are engaged in problem-solving, team-work collaboration, and effective communication.

This process is non-linear and iterative. There is flexibility within the phases that allow for students to return to a phase if needed. Often analysis and improvement will result in additional questions or problems that can be solved through additional design process iterations.

Engineering Design Process



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Connecting Big Ideas

Content integration is a foundational element of STEM education. Discovering and making connections between subject-area disciplines is an important aspect of the instructional design and planning process. The following chart provides initial ideas for content integration across various disciplines.

Science	• TEKS-aligned scientific concepts • Development of models (physical, conceptual, simulations, and mathematical) and prototypes • Scientific Inquiry Investigations– testing materials or other variables related to design elements or science concepts • Science and Engineering Practices
Mathematics	• Mathematically formulate problems, develop models of real and hypothetical phenomena, develop hypotheses, make predictions, conjectures, design devices and protocols, and express and evaluate data • Mathematical computation…Use the four operations to solve problems or develop/maintain a budget • Measurement Tools • Measurement units and unit conversions… Solve problems involving measurement and conversion of measurements from a larger unit to a smaller unit (scientists and engineers work in Metric system) • Ration and proportions - Diagramming to scale • Development and interpretation of graphic representations • Data Collection and Analysis (may or may not apply) depending on the type of design challenge – could be quantitative or qualitative measure of evaluation. • Geometric measurement: Understand concepts of angle and measure angles – slope
English/ Language Arts	• Literary texts • Informational texts – Science and engineering concepts (e.g. architectural design, material engineering, properties of matter, force and motion, etc.) • Multimedia – use of multimedia to develop and share knowledge • Researching – resourcing and using multiple sources to learn about aligned content • Technical writing activities • Verbal presentations related to research synthesis and/or design defense
Social Studies	• Historical problems related to regions/geography • Environmental impacts of natural occurrences and events created by mankind • Regional change over time • Human impact and/or design impact on environment • Technological advancements • Rights and Responsibilities – Develop rights and responsibilities of students during the design process. • Trade/financial literacy if materials cost plays a role during the design challenge (trade-offs) • Economic impacts of designs • Ethical impacts of designs
Arts	• Artistic tools for design, creating, and building • Media…experimenting with materials – structure and function • Use sensory details and descriptive language to identify and describe universal themes, subject matter and ideas • Use digital media to help discover and research universal themes – nature in art • Engage in improvisations or dramatic inquiry around concepts • Aesthetics used in the design • User experience with the product

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Integration Planning Graphic Organizer

INSTRUCTIONS: Use this eye of integration graphic organizer to assist in planning integrated STEM learning experiences. Complete the diagram by identifying the TEKS-aligned content and STEM fluency skills that are connected to the STEM lesson, unit, or project.

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Unit Overview

Unit Summary:

HIGHLIGHTS

5 Es	Description of each 5E phase	Suggested Timeline
Engage:	Activities in the engage phase are designed to elicit prior knowledge and expose misconceptions. In addition, facilitators help to build interest, excitement, and enthusiasm for the topic. Activities might include demonstrations, discrepant events a read-aloud of an interesting text, poem, or current news story, games or other activities that introduce the topic and begin conversation.	**Day 1**
Explore:	The explore phase is a time of active exploration and investigation. Students are developing conceptual knowledge in this phase. Process skills are nurtured as students make observations, collect data, develop concept models and representations, make predictions, and draw conclusions through first- and/or secondhand investigations. Students build a meaningful context in which to used disciplinary content language. They will not have mastered terms at this time. Measurable progress toward achieving the learning objectives becomes apparent in the next phase.	**Days 1 and 2**
Explain:	During the explain phase, the instructor, acting in a facilitation role, uses this phase to offer further explanations and provide additional meaning or information, such as correct terminology. Students communicate conceptual understandings by making evidence-based claims as they share what they have learned using accurate and appropriate terminology. The claims are based on the information and data collected in the explore phase. Some of the products students develop in the explain phase might include responses to writing prompts, explanatory reports, presentations, a class guide to the topic, cause and effect statements, or interviews for a news report. A variety of options for student action and expression is encouraged.	**Day 3**
Elaborate:	The goal of the elaborate phase is to expand and deepen students' knowledge and skill. This phase provides opportunities for students to apply and situate new learning in real-world contexts. This extension of knowledge can be developed through delving deeper into the current concepts, investigation into a related concept, or through an engineering design challenge.	**Days 4 and 5**
Evaluate:	The evaluation is on-going throughout the unit and promotes the use of formative, summative, and performance based assessments. Assessments are used to gather evidence and understanding of student learning or progress throughout the unit, as well as provide insight into students' misconceptions and the degree to which those misconceptions have been addressed. Summative assessments may include but are not limited to performance-based tasks such as the design and development of a solution to a real-world problem.	**Ongoing throughout and Day 6**

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Texas Essential Knowledge and Skills (TEKS)
What are the TEKS that align with this unit? Identify all subject-area TEKS that relate.

Student Learning Outcomes
What should students be able to know and do by the end of this unit? Identify student learning goals aligned with the identified TEKS.

Essential Questions
What overarching essential questions will focus the goals, stimulate conversation, and guide instruction?

Vocabulary	**Student Knowledge/Skills** Prior Concepts Future Applications of Concepts

Common Misconceptions
What are the common misconceptions students might have about the concepts in this unit?

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Assessment Evidence (Performance tasks could be formative or summative)

Formative(s) How will learning be measured as it occurs?

Summative What evidence of learning will demonstrate that a student has met the learning goals?

Resources and Materials

Engage

Explore

Explain

Elaborate

Evaluate

Safety

Think broadly when considering safety. What must be in place to ensure student safety, the safe disposal of materials, use of sharp objects, open flames, etc.?

Additional notes about this unit

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INSTRUCTIONAL PLAN

Considerations: Anticipatory Set, Input and Instruction, Practice, Checks for Understanding, Assessments, Closure, Approximate Timings, Student groupings, etc.

Before/Into	During/Through	After/Beyond
• Set a purpose • Make a plan • Make learning personal • Demonstrate the process • Anticipate final performances • Establish criteria for success	• The 5 Es • Evaluate students' performance • Connect ideas to self, world, other lessons • Extend and challenge thinking • Identify and support struggling students • Assess effectiveness of tools and techniques • Adjust instruction to achieve success	• Pause and reflect on performance • Review, reread, revise, reteach • Identify and remember key ideas • Assess degree of progress and success

Advanced Preparation

5 Es:
Engage, Explore, Explain, Elaborate, Evaluate

ENGAGE Suggested Duration Day 1: 15 – 20 minutes	This portion of the 5E instructional plan should contain an activity(s) which is mentally challenging for students. The students should be so engaged with what they are seeing/doing so that they automatically begin asking questions and wanting to know more. When developing this part of the unit, keep in mind to address questions including: How will you activate student interest? How will you determine what your students already know about the topic? (formative assessment) What can be done at this point to identify and address misconceptions? Where can connections be made to the real world?	
	LITERACY CONNECTIONS: *Use books or other media that help generate questions. (Fries-Gaither & Shiverdecker, 2013, p.29).*	
	TEACHER	**STUDENTS**
	*What is the **TEACHER** doing?*	*What are the **STUDENTS** doing?*
	Teacher and Student Materials:	

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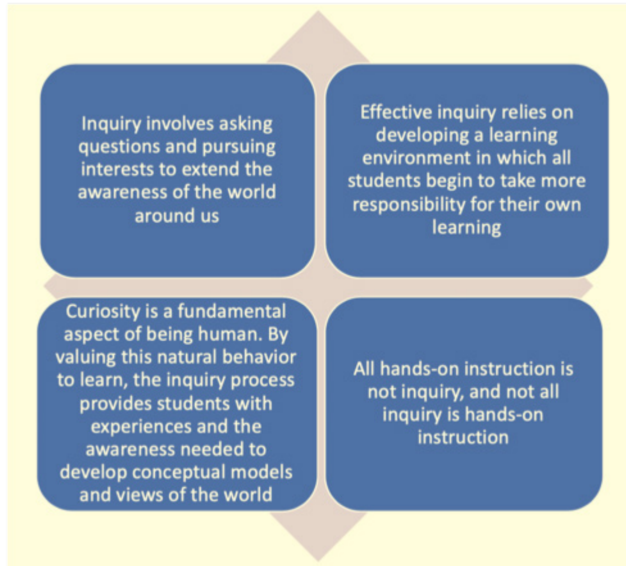
EXPLORE Suggested Duration Day 1: 20-40 minutes Day 2: 40-60 minutes	This portion of the 5E instructional plan is student-centered and allows the students to explore the concepts more in depth. When developing this part of the unit, keep in mind to address questions including: How will the concept be developed? How is this relevant to students' lives? What can be done at this point to identify and address misconceptions?  **INQUIRY** can be use as a tool for exploration. Inquiry is an approach to learning that involves a process of exploring the natural or material world and involves asking and answering questions and making discoveries. *TYPES OF EXPLORATION and INQUIRY* **Guided Discovery** The teacher provides students with a situation, procedure, manipulatives, examples, models, or demonstration. Students make discoveries through experiencing, observing and analyzing, and begin to develop their own conceptions and background knowledge. It is important to pay attention to and address any misconceptions. **Research-based Inquiry** Students engage in the inquiry process by gathering relevant information from multiple print, digital, or authentic sources, while assessing the credibility and accuracy of each source, and integrating the information while avoiding plagiarism. **Guided Scientific Inquiry** Teacher-guided scientific inquiry builds background knowledge around a concept(s) before allowing students to develop their own inquiry. With guided inquiry teachers provide an overall guiding question by which students then develop and conduct the scientific inquiry process. Teachers know what they want their students to understand beforehand, and what the outcome of the inquiry will be. **Student-Driven Scientific Inquiry** Students investigate their own questions that they would like to explore further. Students formulate their own problem or question to investigate and design their own procedures for testing.

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	LITERACY CONNECTIONS: *Use books that pose readily testable questions. Narrative expository and poetry are often perfectly suited to pique student interest. How to books help students plan the investigations they will carry out, and field guides help them identify and classify organisms and objects. Reference and explanation books also are essential as they provide a source of information with which students can compare their own findings. (Fries-Gaither & Shiverdecker, 2013).*	
	TEACHER	**STUDENTS**
	*What is the **TEACHER** doing?*	*What are the **STUDENTS** doing?*
	Teacher and Student Materials:	
EXPLAIN Suggested Duration Day 3: 40-60 minutes	This portion of the 5E instructional plan is when students have an opportunity to clarify and modify their thinking. The teacher provides for the first time, the explanation and terms for what the students are studying. Teachers are encouraged to present material in a variety of ways in order to help students make connections between concepts, representations, and vocabulary. When developing this part of the unit, keep in mind to address questions including: How will you meaningfully connect the explaining activity to the findings from the exploring activity? What products could the students develop and share? How will students share what they have learned? What can be done at this point to identify and address misconceptions?	
	LITERACY CONNECTIONS: *Use books that address the learning objectives, sometimes reading only the pertinent parts. Non-fiction genres can serve as mentor texts – examples of format and writing style after which students can pattern their own work. (Fries-Gaither & Shiverdecker, 2013, p.29).*	
	TEACHER	**STUDENTS**
	*What is the **TEACHER** doing?*	*What are the **STUDENTS** doing?*
	Teacher and Student Materials:	

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<table>
<tr><td rowspan="5">ELABORATE
Suggested Duration
Day 4 40-60 minutes
Day 5: 40-60 minutes</td><td colspan="2">This portion of the 5E instructional plan provides students an opportunity for students to transfer/apply new knowledge with continued support through participation in the Engineering Design Process. Through this process, students construct a deeper understanding of the concepts. Student interaction and collaboration is integral to this phase. When developing this part of the plan please keep in mind to address questions including: How will the new knowledge be reinforced, transferred to new and unique situations, and integrated with related concepts?</td></tr>
<tr><td colspan="2">LITERACY CONNECTIONS: Use books that help students make real-world connections or connect to other concepts. (Fries-Gaither & Shiverdecker, 2013, p.29).</td></tr>
<tr><td>TEACHER</td><td>STUDENTS</td></tr>
<tr><td>What is the TEACHER doing?

Teachers are facilitators of the Engineering Design Process
• Refer to the Engineering Design Process Facilitator’s Guide.</td><td>What are the STUDENTS doing?

Students are active participants in the Engineering Design Process:
• IDENTIFY the problem, constraints, and user need
• IMAGINE – explore materials, brainstorm ideas, and imagine user experience
• Develop a PLAN and gather materials
• CREATE, build, and test the product
• IMPROVE the product through analysis, and modifying design/product</td></tr>
<tr><td colspan="2">Teacher and Student Materials:</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="3">EVALUATE
Suggested Duration
On-going and
Day 6: 15-20 minutes</td><td colspan="2">This portion of the 5E lesson has a dual purpose. It is designed for the students to continue to elaborate on their understanding and to evaluate what they know now and what they have yet to figure out. Evaluation of student understanding should take place throughout all phases of the instructional model. The evaluation stage, however, is when the teacher determines the extent to which students have developed a meaningful understanding of the concepts. When developing this part of the plan, keep in mind to address questions including: What opportunities will students have to express their thinking? When will students reflect on what they have learned? How will you measure learning as it occurs? What evidence of student learning will you be looking for and/or collecting?</td></tr>
<tr><td>Formative(s)
How will you measure learning as it occurs?</td><td>Summative(s)
What evidence of learning will demonstrate to you that a student has met the learning goals?</td></tr>
<tr><td colspan="2">Teacher and Student Materials:</td></tr>
</table>

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Additional Considerations	
DIFFERENTIATION	*How will you ensure that all students have access to this learning opportunity?* **Accomodations/Modifications** ELL students; students with a visual impairment, hearing impairment, orientation/mobility challenges, other specific abilities/challenges.
ADDITIONAL RESOURCES	*What additional resources might be useful to teachers and/or students?* **Literature:** **Websites for students:** **Websites for teachers:** **Video Clips:** **Technology Apps/Tools:**

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Engineering Design Process
FACILITATOR GUIDE

The Engineering Design Process is an instructional method that can be used to teach and apply a variety of concepts in an integrated fashion. Students engage with integrated concepts from multiple disciplines and utilize design thinking as a mechanism to design a solution to an authentic problem. There are multiple model variations of the engineering design process, however they all share the basic practices of identifying questions or defining problems, imagining/brainstorming, planning a design, creating and testing a design, and improving the design. Throughout the process students are engaged in the STEM Fluency skills of collaboration, communication, critical thinking, creativity, innovation, adaptability, resilience, and time/resources management.

NOTE: The use of a notebook or journal is encouraged for student learning evidence and reflection through each phase of the engineering design process.

DEVELOP CONTEXT

- ☐ What questions do students have about the concepts introduced throughout the unit?
- ☐ Pose “What If” questions.
- ☐ Identify real-world problems or issues in the community, region, or in other parts of the world that relate to the concepts in the unit.

PREPARATION

Students complete preparation page:

A. Identify the problem or issue
   - State the problem. What is the purpose for having to develop this design or solution?
   - Based on prior activities, students identify vocabulary words and/or concepts that relate to the problem.

B. Class Developed Rubric for the design process:
   As a class, assist students in determining the evidence that they will provide to you, the facilitator, to show that they have completed each phase of the design process. An example is provided.

MY DESIGN PROCESS WORK RUBRIC

Steps of the Design Process	What will i be doing during each part of the design process?	Score
Identify	*ask questions, identify criteria, identify constraints, identify user needs*	
Imagine	*sketch, written description, whiteboarding, video of planning, examples of support structures, multiple ideas, research*	
Plan	*proposal, design sketch, group roles, materials list, blueprints (measurements/labels), instructions and procedures, timeline, clear expectations*	
Create	*prototype, work log, video/photos, journaling/blog entries, notes in interactive notebook*	
Improve	*summary paragraph, video/photos, work log, explanation, documented changes to process documents, new blueprints, a new or improved prototype*	
Communicate	*Presentation, verbal defense related to design choices, feedback given and received, video/photos, poster, infographic, exhibition, townhall mtg.*	

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DESIGN PROCESS

1. **IDENTIFY** the problem – "What do we need to know in order to design ____________________" (Write student questions on the board)

   Example of student questions might be:
   - What materials do we have?
   - How much time do we have to plan, design and build?
   - What is the environment like? (Climate)
   - What is our budget?
   - Do we have space limitations?
   - What natural resources are available?
   - What are the needs of the user/audience (empathy)?

The facilitator should answer student questions to the best of his/her ability, as these questions will help to determine criteria and constraints.

CRITERIA: Criteria are rules or directions that must be followed; they are the requirements that must be met. State the criteria for students and write on the board.

Facilitator – Develop and write criteria here:

CONSTRAINTS: Constraints are restrictions or limitations posed by the context of the problem. These can be written on the board next to their original questions from the IDENTIFY phase.

Facilitator – Develop and write criteria here:

Guiding question prompts for students:

1. Our goal is…
2. The materials we can use are…
3. Some things we have already learned about this topic are…

Student Groups: Divide student engineers into engineering teams (groups of 2-4 students is suggested)

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2. **IMAGINE** - Brainstorm
    A. First, provide students with the opportunity to brainstorm individually and to develop multiple ideas. They can record these ideas in a notebook/journal, on a whiteboard, or blank sheet of paper, etc. Students should imagine the user experience to gain a sense of empathy.

    B. Next, students will share their ideas with their team with the understanding that the team must develop one cohesive design incorporating at least one component from each team member and get the facilitator's approval.

3. **PLAN** – Each engineering team designs a plan
    A. Students make a technical drawing of their representation/model of their design. The technical drawing should include labels and materials being used.

    B. Students write a technical description about their design. The technical description should include measurements and mechanical movements if applicable.

    C. Students develop a procedure list that they will use to create their design.
    - Even though this is a team plan, consider having each individual develop their own drawing, description, and written procedure.

4. **CREATE** - Build, Test, & Evaluate
    A. Students build their designs out of available materials, taking into consideration the criteria and constraints of the design challenge.

    B. TESTING PROCEDURES:
    - Develop testing procedures by facilitating a whole-class discussion or allow each engineering team to develop their own testing procedures.
    - Students will test their designs using the outlined procedures, and gather quantitative and/or qualitative data.

5. **IMPROVE** - Students reflect and revise their designs
    A. Students will analyze their designs and the results of testing the design. Students will determine how they can improve the design.

    B. Provide time for students to make changes to their model.

6. **COMMUNICATE** -
    A. Provide students with time to reflect upon the process and their end products. See work rubric for examples. (e.g. journaling, quick-write, self-assessment – rubric, peer assessment, discussion, report.
    - Possible reflection prompts may include:
        - Compare the different models by the students. What components are most effective for reinforcing hills? What is your evidence and reasoning?
        - Describe what you did during each phase of the design process.

    B. Provide students with opportunities to share their work within the classroom and outside of the classroom. (e.g. presentations, exhibition or display, sharing with other classes, presentation at a STEM event, marketing pitch to a panel of experts, etc.)

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