EngrTEAMS

EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Team-Based Targeted Mathematics-Science Partnership

Electromagnetic Claw Game: Diggin' For Fools' Gold

Grades 4-6

University of Minnesota
STEM Education Center
NSF
INSPIRE Research Institute for Pre-College Engineering
Purdue University

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About EngrTEAMS

Purpose

The project is designed to help 200+ teachers develop engineering design-based curricular units for each of the major science topic areas within the Next Generation Science Standards, as well as data analysis and measurement standards for grades 4-8.

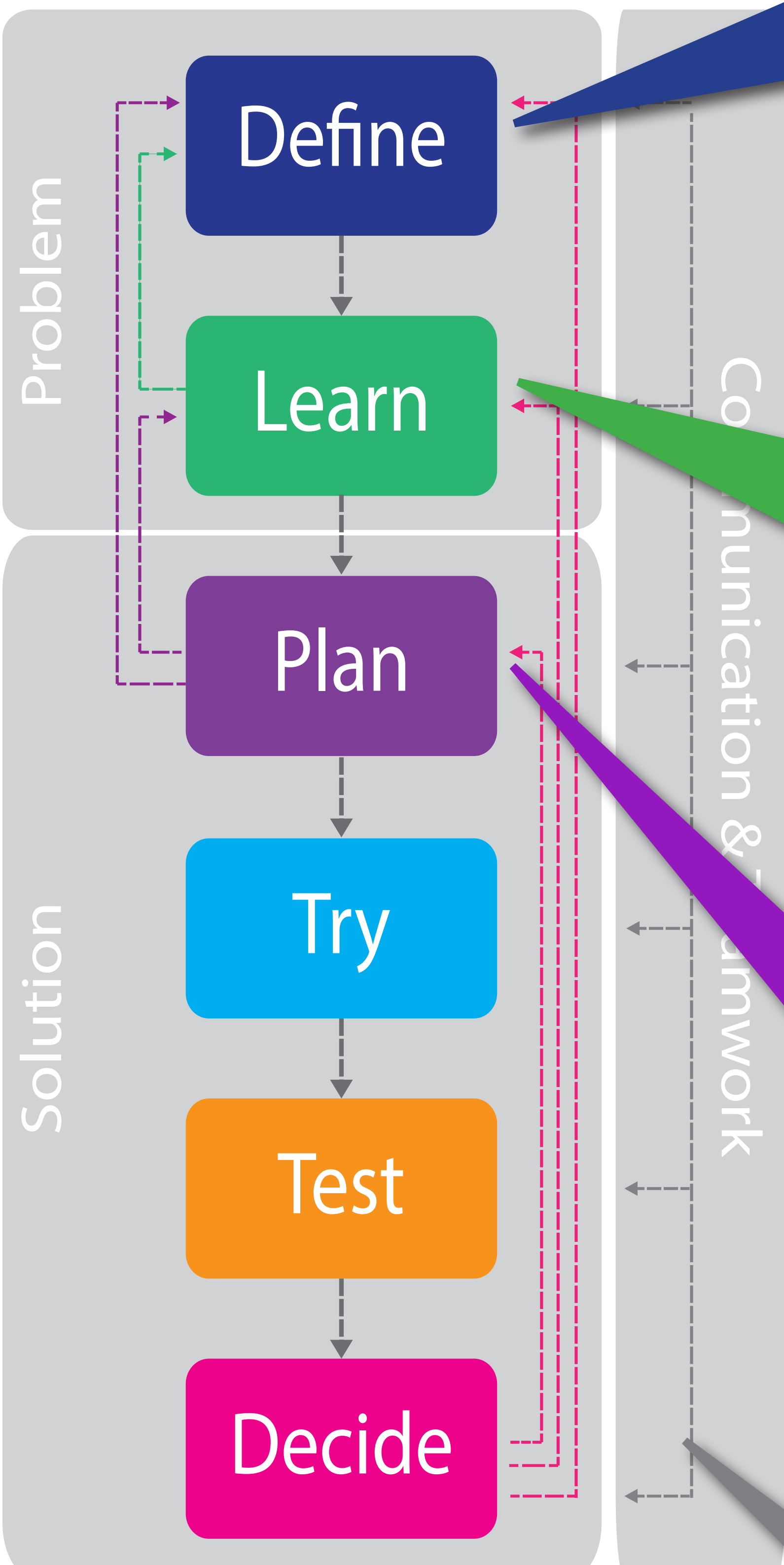
With a focus on vertical alignment and transition from upper elementary to middle-level, this project will impact at least 15,000 students over the life of the grant.

To learn more about the project and find additional curricular units go to www.engrteams.org.

Overview: Engineering Design Process

Engineering Design Process

A way to improve



DEFINE THE PROBLEM

- Who is the **client**?
- What does the client need?
- Why does the client need it?
- Who is the **end user**?
- Why might the end user want it?
- What are the **criteria** (requirements) and **constraints** (limits) of the solution?

Problem Scoping:
WHO needs **WHAT** because **WHY**

LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed?
  - What science/math knowledge will be needed?
  - What materials will be needed?
- What has already been done to solve the problem?
- What products fill a similar need?
- How should we measure success and improvement?

PLAN A SOLUTION

- Continue to specify the criteria/ constraints
- Generate ideas of possible solutions
- Develop multiple solution paths
- Consider **constraints, criteria**, and **trade-offs** (criteria that compete with one another)
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages, etc.)

COMMUNICATION

- Communicate the solution clearly and make sure it is easily understandable
- Use **evidence** to support why the client should use your solution

Overview: Engineering Design Process

TRY A SOLUTION

- Put the plan into action
- Consider risks and how to optimize work
- Use criteria/constraints and consider trade-offs from the problem/plan to build a **prototype** (a testable representation of a solution), **model**, or **product**

TEST A SOLUTION

- Consider testable questions or hypotheses
- Develop experiments or rubrics to determine if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

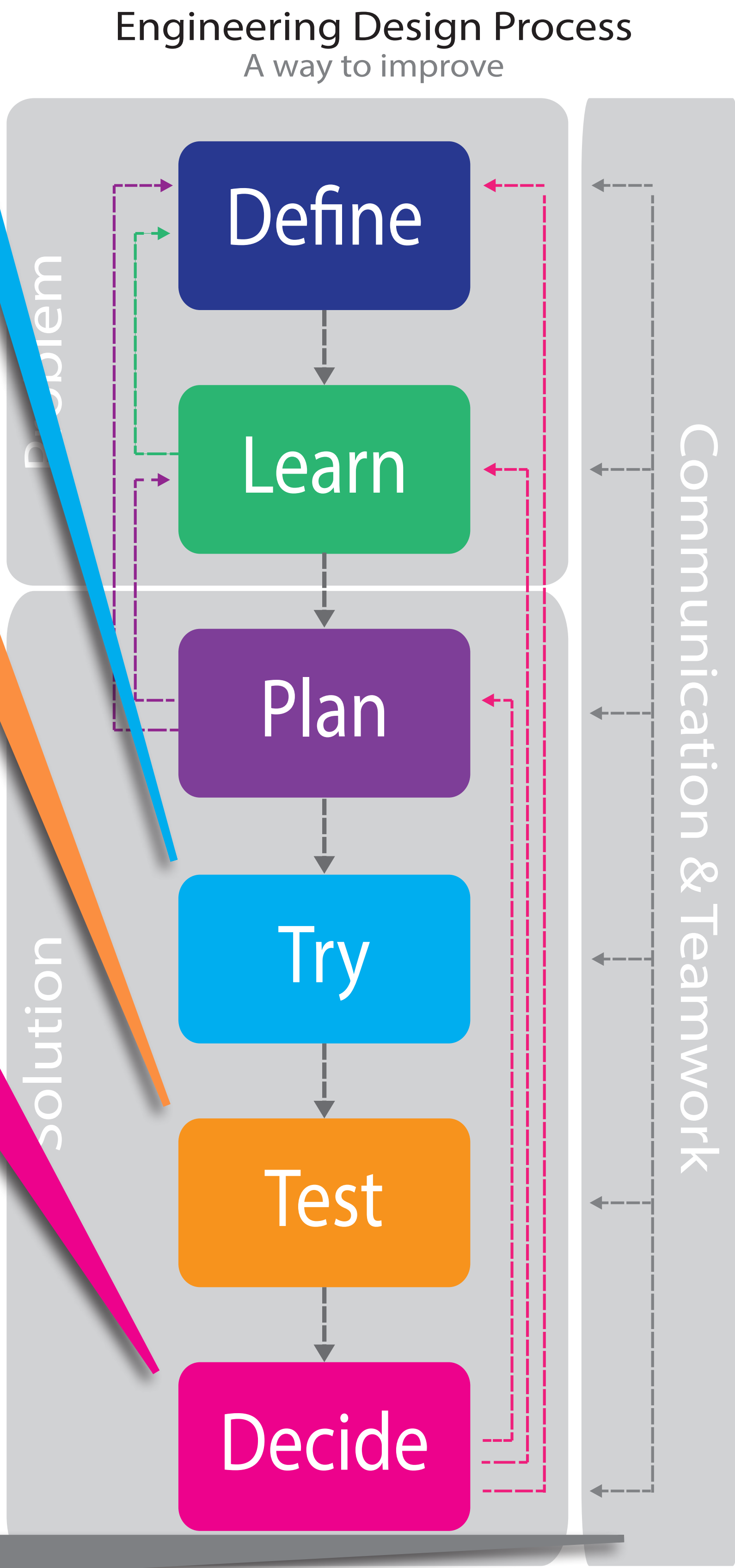
DECIDE IF THE SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does the design meet the criteria and constraints?
- How could the design be improved based on test results and feedback from the client/user?

Iterative nature of design: Always consider which step should be next!

TEAMWORK

- Discuss in teams how the solution meets the criteria and needs of the client
- Consider different viewpoints from each teammate



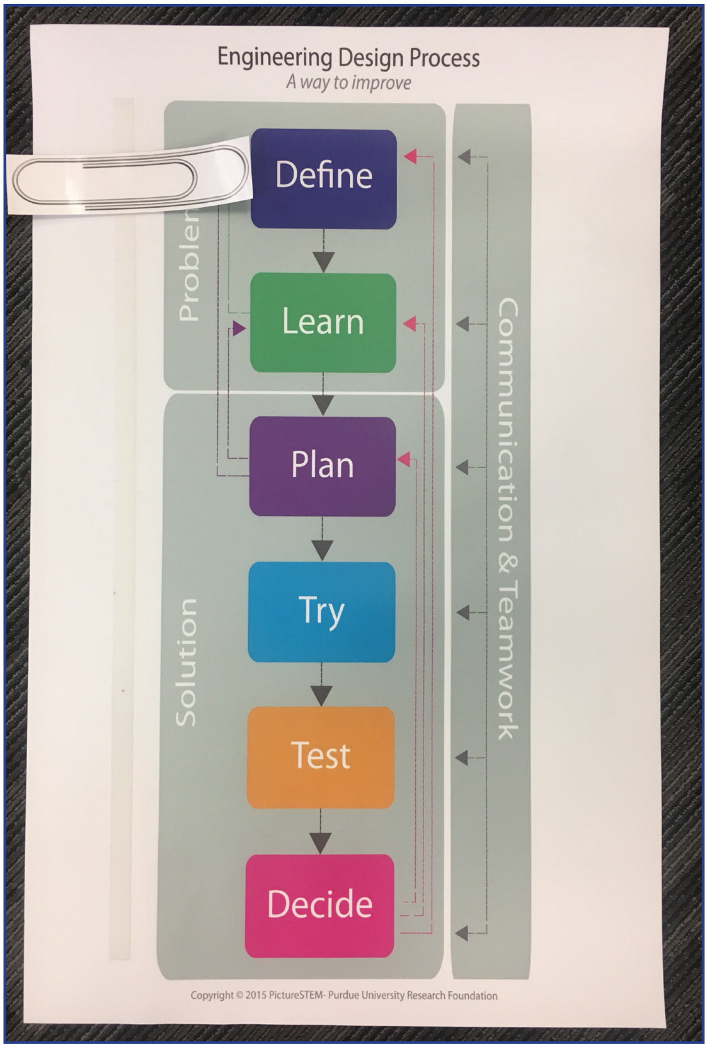
Overview: How to make EDP sliders

HOW TO CREATE THE POSTER

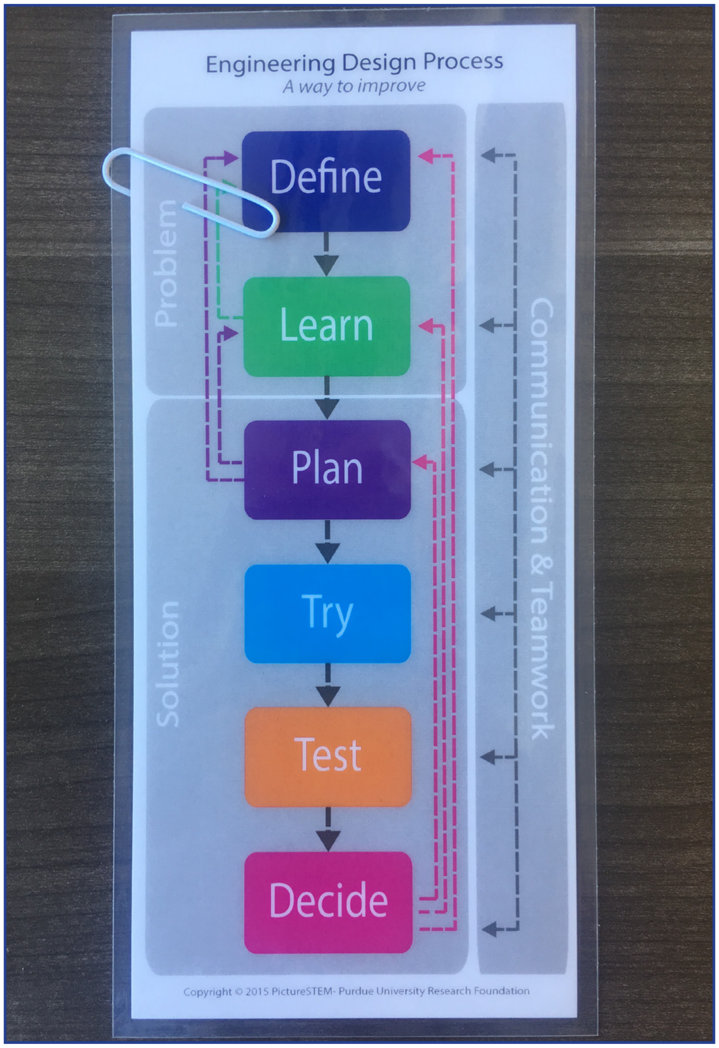
1. Download the high-quality PictureSTEM Slider Poster and the paper clip images from PictureSTEM.org.
2. Print the poster and the paper clip on poster-sized paper and cut to size. High-gloss or semi-gloss paper is the best choice.
3. Use self-sticking Velcro on the back of the paper clip and down the side of the poster so that the paper clip can be placed to point at all 6 sections of the slider.

HOW TO CREATE INDIVIDUAL SLIDERS

1. Print the sliders on the opposite page - enough for one slider per student in your class.
2. Cut the sliders apart.
3. Laminate the sliders individually.
4. Use a jumbo paper clip as the pointer for each slider.

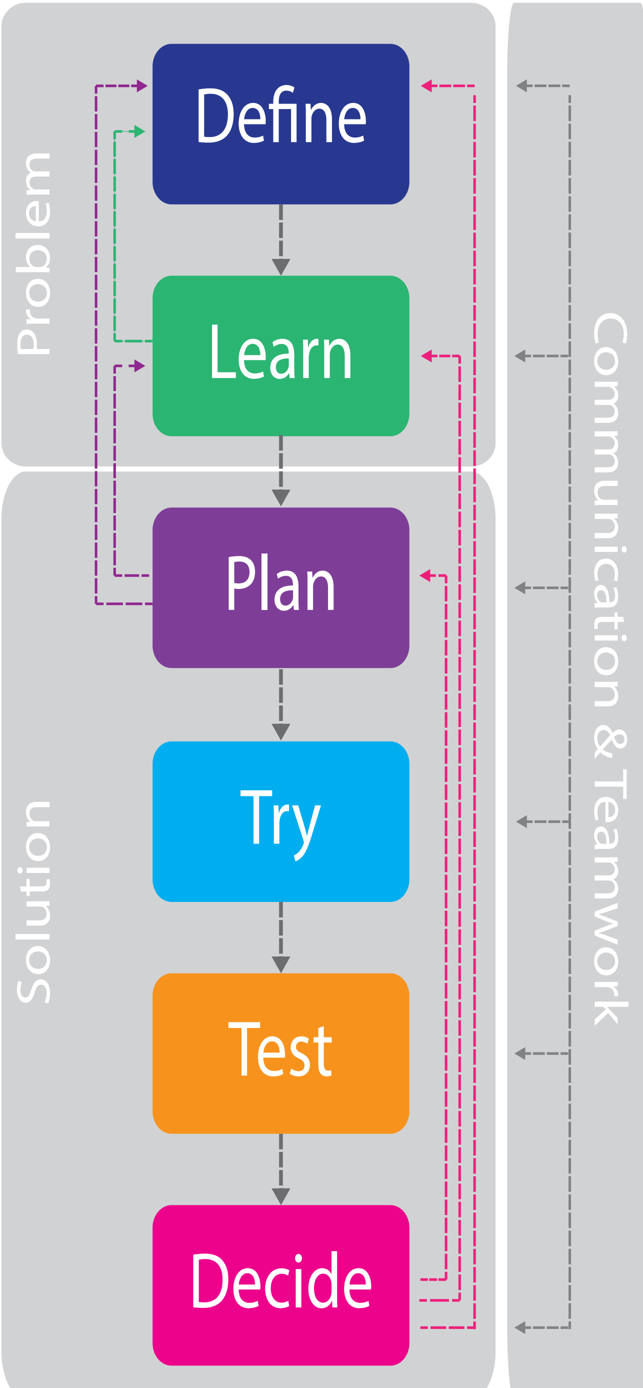


Poster

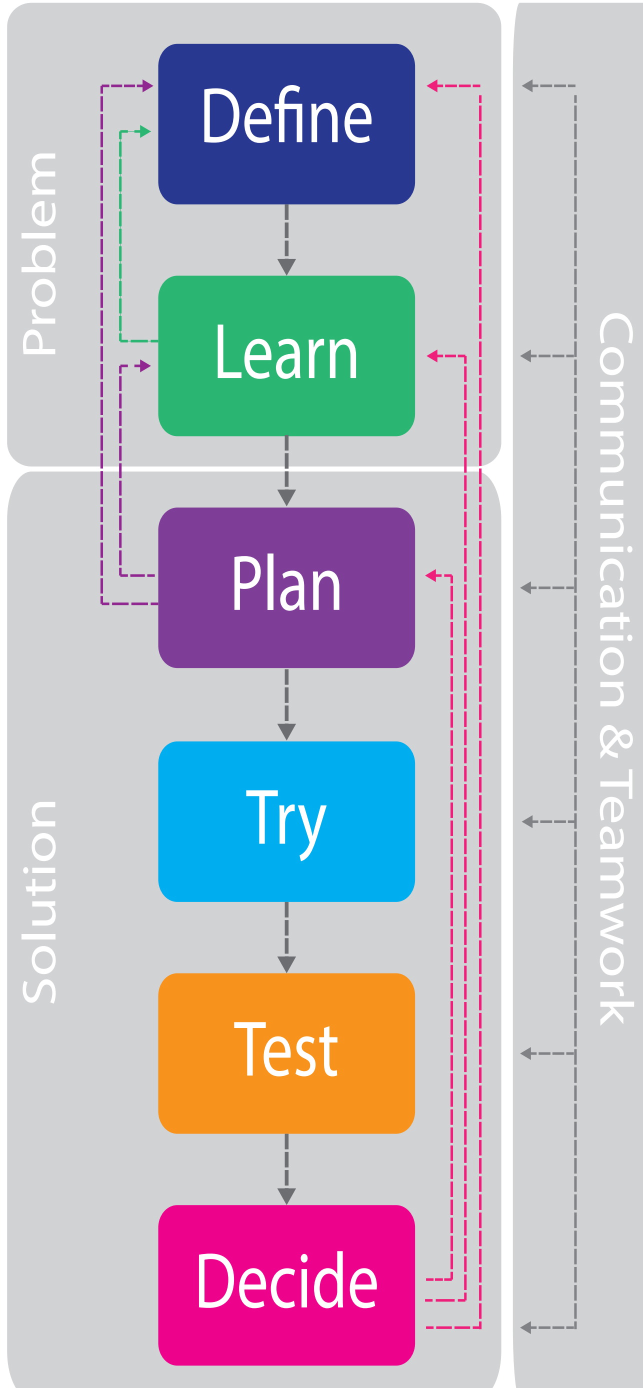


Individual slider

Engineering Design Process
A way to improve



Engineering Design Process
A way to improve



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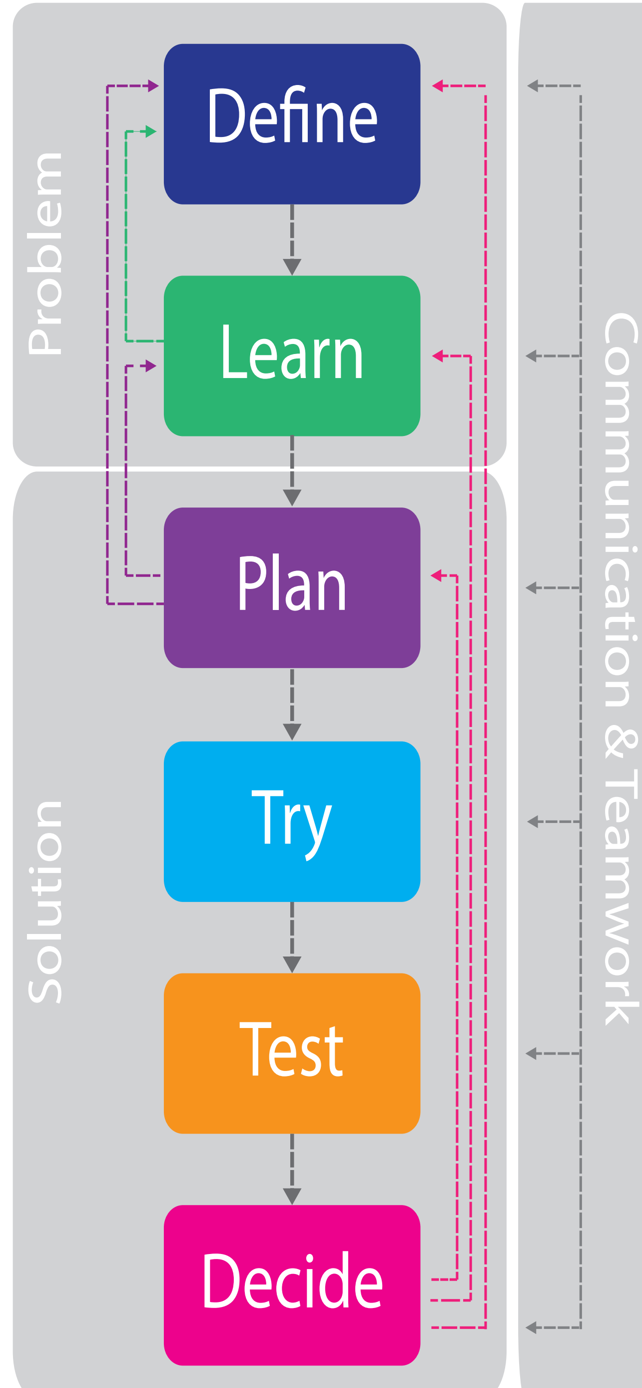
Engineering Design Process
A way to improve



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Overview: Unit Description

Grade Levels:

4 or 5

Approximate Time Needed to Complete Unit:

Twelve-fourteen 50-minute class periods

Unit Summary

Claw games are rigged! Students discover that claw games found at arcades or shopping malls are often rigged so that players are very unlikely to win. Galactic Games needs the students to help redesign the game to make it more fair but also still challenging and fun to play. Specifically, they want to use an electromagnetic arm instead of the claw, and the students are tasked with designing that electromagnetic arm. Students learn about magnets, magnetic materials, and electromagnets as they prepare to design their electromagnetic claw games. Once they have created their designs, they test them to see how reliably they can pick up and move toys. The unit concludes with students presenting their final designs to the client in a presentation.

Science Connections	Technology & Engineering Connections	Mathematics Connections
magnets, magnetic materials, electromagnets, designing experiments, claims & evidence	Electrical Engineering, graphing software	data analysis, summary statistics (mean, median, etc.), lines of best fit

Unit Standards

Next Generation Science Standards

- **5-PS1-3:** Make observations and measurements to identify materials based on their properties.
- **3-5-ETS1-1:** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- **3-5-ETS1-2:** Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- **3-5-ETS1-3:** Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
- **MS-PS2-3:** Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.
- **MS-ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-2:** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **MS-ETS1-3:** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- **MS-ETS1-4:** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Overview: Unit Description

Common Core State Standards - Mathematics

- **MP1:** Make sense of problems and persevere in solving them.
- **MP2:** Reason abstractly and quantitatively.
- **MP3:** Construct viable arguments and critique the reasoning of others.
- **MP4:** Model with mathematics.
- **MP5:** Use appropriate tools strategically.
- **MP6:** Attend to precision.
- **4.MD.B.4:** Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8). Solve problems involving addition and subtraction of fractions by using information presented in line plots.
- **5.MD.B.2:** Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8). Use operations on fractions for this grade to solve problems involving information presented in line plots.
- **6.SP.B.4:** Display numerical data in plots on a number line, including dot plots, histograms, and box plots.
- **6.SP.B.5:** Summarize numerical data sets in relation to their context, such as by:
  - **6.SP.B.5.A:** Reporting the number of observations.
  - **6.SP.B.5.B:** Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.

Unit Assessment Summary

Throughout this unit, students individually maintain an engineering notebook to document their engineering design processes. In this, students make observations, collect data, and plan for their design. Part of the engineering notebook includes answering specific questions related to that day's activities. You may choose to post the questions on your overhead/PowerPoint slides, or give the students printed versions (included as duplication masters in each applicable lesson) to tape into their notebooks. Students use their notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students reflect on their work throughout the design process. This is important for modeling what real-life engineers do. **Collect the engineering notebooks at the end of each class.** You will use the notebooks to assess student learning through their design process. Provide feedback to students on their notebook responses - rubrics are provided. You are encouraged to assign points for responses in the engineering notebooks. **Provide feedback often - especially lessons for which rubrics are provided.**

- The notebook pages are often set up as handouts in each lesson. If you prefer to use notebooks without having students paste copied pages in them, there is an appendix at the end of this unit that includes notebook prompts and how to have students title each entry.
- The final summative piece of this unit requires students to communicate to the client recommending a design and justifying its success as a solution to the engineering problem.

Overview: Lesson Summaries

Lesson 1: Claw Games are Rigged!: Problem Scoping

Students are introduced to the engineering design challenge: claw games are rigged, and Galactic Games wants to redesign their game. Students engage in problem scoping as they discuss and identify the design challenge described in a memo from the client. Students also review engineering and the engineering design process and work with their teams to create a team charter. They use this team charter to support their work in teams and to hold each other and themselves accountable throughout the unit.

Lesson 2: Magnets & Magnetic Materials

Before beginning their design challenge, students learn background information on magnets and magnetic materials. This will help them make decisions about the types of materials that are appropriate for their design solution. In this lesson, students work through four stations where they examine different aspects of magnetism. Students 1) test a variety of materials to see which ones are magnetic; 2) determine if all magnets have both north and south poles; 3) examine the effect of size and shape on magnet strength; and 4) determine if magnet fields can pass through other materials. The lesson concludes with students summarizing what they have learned about magnets with claims supported by evidence.

Lesson 3: Electromagnet Exploration/Variable Sort

In this lesson, students investigate different aspects of electromagnets that impact the way magnets works. Students explore how they can use an electromagnet to pick up magnetic materials in order to determine different ways the electromagnet can be modified. This will allow them to develop a list of specific variables that they feel might impact the strength or performance of the electromagnet. Once they have generated this list, they discuss how they might test each variable. In the next lesson, they will actually begin to test one of these variables.

Lesson 4: Testing the Number of Coils

One of the variables that students identify as possibly impacting the strength or performance of the electromagnet is the number of coils on the nail. In this lesson, students carry out an experiment to test this variable. Using several different numbers of coils, students collect data on how many small hex nuts the electromagnet can pick up. With this data, the class generates a scatterplot showing the number of hex nuts versus the number of coils. Students examine the data both graphically and tabularly to try to identify how the number of coils impacts the strength of the electromagnet. The lesson concludes with the students writing claims supported with evidence about the effect of coils on electromagnets.

Overview: Lesson Summaries

Lesson 5: Electromagnet Team Experiments

In this lesson, teams choose another variable to test. Again, they collect data for several different values of the variable and create tables/visual displays to look for patterns in the data. Students then create a poster to share their experiment and results with the class. These posters contain detail about the experiments as well as claims supported by evidence about the effect of their variable on the strength of the electromagnet.

Lesson 6: Plan and Try

Using the information they learned about magnets and electromagnets in the preceding lessons, students design and build an electromagnetic claw arm prototype for Galactic Games. Students justify their design choices using data and evidence from previous lessons in an Evidence Based Reasoning graphic.

Lesson 7: Test and Decide

Students then test their design by repeatedly attempting to pick up and transport a small toy with a washer attached from one box to another. After testing their electromagnets, they reflect on their design decisions based on the data they collected.

Lesson 8: Redesign: Plan, Try

After the initial design and test with one toy, the client asks the students to redesign and retest their new designs, but this time with several different toys of different sizes, more like an actual claw game. Students use what they learned while testing their original designs to make a new plan for their electromagnetic claw arm, and they will justify those decisions. Time permitting, students will begin testing their new designs by moving toys with a variety of different sizes and weights from one container to another

Lesson 9: Redesign: Decide, Share

Once students have finished testing their redesigned claw arms, the students present their best design to the client through a poster presentation. The poster describes the results of the tests, as well as the reasoning behind their design choices.

Overview: Unit Overview

Lesson	Time Needed	Duplication Masters & Educator Resources	Objectives The student will be able to:
1: Claw Games are Rigged: Problem Scoping	one-two 50-minute class periods	**DUPLICATION MASTERS** • 1.a. What is Engineering? • 1.b. Client Memo 1: Claw Games are Rigged • 1.c. Claw Machines are Rigged Article • 1.d. Client Memo 1 Part 2 • 1.e. Problem Scoping • 1.g. Client Memo 1 Part 3 **EDUCATOR RESOURCES** • 1.f. Problem Scoping Rubric • 1.h. Problem Scoping Question Response Template	• identify the problem and client within the engineering design challenge. • describe the problem within the engineering design challenge. • establish team norms to help their team work well together.
2: Magnets & Magnetic Materials	two 50-minute class periods	**DUPLICATION MASTERS** • 2.a. Client Memo 2 • 2.b. Magnets Investigation • 2.c. Odd One Out • 2.d. EDP Self-Assessment	• make a claim supported with evidence. • explain how magnets interact with each other and other materials. • evaluate their role in an academically minded team.
3: Electromagnet Exploration/Variable Sort	one 50-minute class periods	**DUPLICATION MASTERS** • 3.a. Client Memo 3 • 3.c. Concept Cartoon **EDUCATOR RESOURCES** • 3.b. Critical Response Protocol Image	• describe how electromagnets work. • identify possible ways to change electromagnetic strength.
4: Testing the Number of Coils	two-three 50-minute class periods	**DUPLICATION MASTERS** • 4.a. Client Memo 4 • 4.b. Talking Probe	• identify ways to change electromagnetic strength. • identify the different variables in an experiment. • create a data table with labels. • create a claim, supported with evidence.
5: Electromagnet Team Experiments	two-three 50-minute class periods	**DUPLICATION MASTERS** • 2.d EDP Self-Assessment • 5.a. Client Memo 5	• experiment with electromagnets to collect data that will inform decisions for solutions/designs in the engineering design challenge. • create a data table with labels. • create a graph of data with labels. • identify patterns in data. • evaluate their role in an academically minded team.

Materials
• **Per class:** Engineering Design Process poster, **(optional)** claw game, **(optional)** assortment of prizes (candy, erasers, bouncy balls, toy rings, etc.) • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per class:** Engineering Design Process poster, (8) bar magnets (north & south poles marked), (4) rectangular magnets (unmarked), (4) steel paper clips, (4) steel washers, (4) bear counters, (2) ring magnets, (2) disc magnets, (2) rectangular magnets (small), (2) neodymium magnets (small), (2) horseshoe magnets, assortment of magnetic and non-magnet materials • **Per team:** (4) 3”x5” notecards • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per class:** Engineering Design Process poster • **Per team:** 10 ft copper wire (insulated, 20 gauge), (1) 3-1/2 in. steel nail, (2) alligator clips, (100) hex nuts (size 6-32 machine screws), (2) D-batteries, (2) D battery holders, 2 in. copper wire (bare, 20 gauge) • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per class:** Engineering Design Process poster • **Per team:** 10 ft copper wire (insulated, 20 gauge), (1) 3-1/2 in. steel nail, (2) alligator clips, (100) hex nuts (size 6-32 machine screws), (2) D batteries, (2) D battery holders, 2 in. copper wire (bare, 20 gauge) • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per class:** Engineering Design Process poster, (4) 10 ft insulated copper wire (18 and 24 gauge), (12) alligator clips, (4) AA batteries, (4) C batteries, (8) D batteries, (4) battery holders (sizes AA, C and D), (4) 3-1/2 in. aluminum nail, (4) 3-1/2 in. galvanized steel nail, (4) 2-1/2 in. steel nail, (4) 3 in. steel nail, (4) 4 in. steel nail, (4) 4 in. steel finishing nail, (4) 4 in. steel bolt (thick), (4) 3-1/2 in. wooden dowel, (4) 3-1/2 in. plastic rod • **Per team:** 10 ft insulated copper wire (20 gauge), (1) 3-1/2 in. steel nail, (2) alligator clips, (100) hex nuts (size 6-32 machine screws), (2) D batteries, (2) battery holders (size D), (1) 3-1/2 in. stainless steel nail, (1) poster or chart paper, (1) pack of markers • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils

Overview: Unit Overview

Lesson	Time Needed	Duplication Masters & Educator Resources	Objectives The student will be able to:
6: Plan and Try	one 50-minute class periods	**DUPLICATION MASTERS** • 6.a. Client Memo 6 • 6.b. Design Ideas Planning Protocol • 6.e. Evidence-Based Reasoning • 6.h. Design & Justification **EDUCATOR RESOURCES** • 6.c. Design Ideas Planning Protocol Rubric • 6.d. Teacher Observation Protocol: Try • 6.f. EBR Rubric • 6.g. EBR Instructions	• evaluate their role in an academically minded team. • use evidence from problem scoping to generate multiple initial ideas for a design solution.
7: Test and Decide	one 50-minute class periods	**DUPLICATION MASTERS** • 7.b. Test Solution Ideas **EDUCATOR RESOURCES** • 7.a. Teacher Observation Protocol: Test • 7.c. Test Solution Ideas Rubric	• evaluate their role in an academically minded team. • analyze the data from testing variables of electromagnets to make decisions in their design/solution to the engineering design challenge. • make a claim supported with evidence. • evaluate their team's solution to the engineering design challenge.
8: Redesign: Plan, Try	one 50-minute class periods	**DUPLICATION MASTERS** • 8.a. Client Memo 7 **EDUCATOR RESOURCES** • 8.b. Teacher Observation Protocol: Redesign	• evaluate their team's solution to the engineering design challenge. • revise their design/solution to the engineering design challenge.
9: Redesign: Decide, Share	one 50-minute class periods	**DUPLICATION MASTERS** • 9.a. Final Presentation Rubric • 9.b. Redesign Evaluation • 9.d. Unit Reflection **EDUCATOR RESOURCES** • 9.c. Redesign Evaluation Rubric • 9.e. Unit Reflection Rubric	• create a presentation to effectively address their audience and portray their ideas. • make a claim, supported with evidence.

Materials
• **Per class:** Engineering Design Process poster, (50) steel washers, (1) hot glue gun with hot glue sticks, (10) duck counters, (24) D batteries, (24) C batteries, (24) AA batteries, (8) 10 ft insulated copper wire (18, 20, and 22 gauge), (24) alligator clips, (24) battery holders (sizes AA, C, and D), (8) 3-1/2 in. steel nail, (8) 3-1/2 in. stainless steel nail, (8) 3-1/2 in. aluminum nail, (8) 3-1/2 in. galvanized steel nail, (8) 2-1/2 in. steel nail, (8) 3 in. steel nail, (8) 4 in. steel nail, (8) 3-1/2 in. steel bolt (thin), (8) 3-1/2 in. steel bolt (thick), various other materials from Lessons 4 and 5. • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per class:** Engineering Design Process poster, (50) steel washers, (1) hot glue gun with hot glue sticks, (10) duck counters, (24) D batteries, (24) C batteries, (24) AA batteries, (8) 10 ft insulated copper wire (18, 20, and 22 gauge), (24) alligator clips, (24) battery holders (sizes AA, C, and D), (8) 3-1/2 in. steel nail, (8) 3-1/2 in. stainless steel nail, (8) 3-1/2 in. aluminum nail, (8) 3-1/2 in. galvanized steel nail, (8) 2-1/2 in. steel nail, (8) 3 in. steel nail, (8) 4 in. steel nail, (8) 3-1/2 in. steel bolt (thin), (8) 3-1/2 in. steel bolt (thick), various other materials from Lessons 4 and 5. • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per class:** Engineering Design Process poster, (50) steel washers, (1) hot glue gun with hot glue sticks, (10) duck counters, (10) rubber duckies, (10) bear counters, (10) bouncy balls, (10) insect toys, (10) toy cars, (24) D batteries, (24) C batteries, (24) AA batteries, (8) 10 ft insulated copper wire (18, 20, and 22 gauge), (24) alligator clips, (24) battery holders (sizes AA, C, and D), (8) 3-1/2 in. steel nail, (8) 3-1/2 in. stainless steel nail, (8) 3-1/2 in. aluminum nail, (8) 3-1/2 in. galvanized steel nail, (8) 2-1/2 in. steel nail, (8) 3 in. steel nail, (8) 4 in. steel nail, (8) 3-1/2 in. steel bolt (thin), (8) 3-1/2 in. steel bolt (thick), various other materials from Lessons 4 and 5. • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils
• **Per team:** (1) poster or chart paper, (1) pack of markers • **Per student:** (1) engineering notebook, (1) Engineering Design Process slider, (2) different color writing utensils

Master Material List

	Material	Lessons Where Material is Used
Per classroom	Engineering Design Process poster	all
	(optional) claw game*	1
	(optional) assortment of prizes (candy, erasers, bouncy balls, toy rings, etc.)*	1
	(8) bar magnets (north & south poles marked)	2
	(2) disc magnets	2
	(2) horseshoe magnets	2
	(2) neodynium magnets (small)	2
	(2) rectangular magnets (small)	2
	(4) rectangular magnets (unmarked)	2
	(2) ring magnets	2
	(4) steel paper clips*	2
	(50) steel washers	2, 6, 7, 8
	assortment of magnetic and non-magnet materials	2
	(24) AA batteries	4, 5, 6, 7, 8
	(24) C batteries	4, 5, 6, 7, 8
	(24) D batteries	3, 4, 5, 6, 7, 8
	(24) battery holders (sizes AA, C, and D)	3, 4, 5, 6, 7, 8
	(24) alligator clips	3, 4, 5, 6, 7, 8
	(8) 10 ft insulated copper wire (18, 20, and 22 gauge)	3, 4, 5, 6, 7, 8
	(8) 2-1/2 in. steel nail	5, 6, 7, 8
	(8) 3 in. steel nail	5, 6, 7, 8
	(8) 3-1/2 in. steel nail	3, 4, 5, 6, 7, 8
	(8) 4 in. steel nail	5, 6, 7, 8
	(4) 4 in. steel bolt (thick)	5, 6, 7, 8
	(4) 4 in. steel finishing nail	5, 6, 7, 8
	(8) 3-1/2 in. aluminum nail	5, 6, 7, 8
	(8) 3-1/2 in. galvanized steel nail	5, 6, 7, 8
	(4) 3-1/2 in. plastic rod	5
	(8) 3-1/2 in. stainless steel nail	5, 6, 7, 8
	(8) 3-1/2 in. steel bolt (thick)	5, 6, 7, 8
	(8) 3-1/2 in. steel bolt (thin)	5, 6, 7, 8
	(4) 3-1/2 in. wooden dowel	5
	(10) bear counters	2, 8
	(10) bouncy balls	8
	(10) duck counters	6, 7, 8
	(10) insect toys	8
	(10) rubber duckies	8

Master Material List

	Material	Lessons Where Material is Used
	(10) toy cars	8
	hot glue gun with hot glue sticks*	6, 7, 8
Per team	(4) 3"x5" notecards*	2
(assuming 3 students	(100) hex nuts (size 6-32 machine screws)	3, 4, 5
per team)	2 in. copper wire (bare, 20 gauge)	3, 4
	(2) poster or chart paper*	9
	(1) pack of markers*	9
Per student	(1) engineering notebook	all
	(1) Engineering Design Process Slider	all
	(2) different color writing utensils*	all

*required material not included in kit

LESSON 1

Claw Games are Rigged!: Problem Scoping

Lesson Objectives

Students will be able to:

- identify the problem and client within the engineering design challenge.
- describe the problem within the engineering design challenge.
- establish team norms to help their team work well together.

Time Required

one-two 50-minute class periods

Materials

Per class:

- Engineering Design Process poster
- **(optional)** claw game
- **(optional)** assortment of prizes (candy, erasers, bouncy balls, toy rings, etc.)

Per student:

- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Standards Addressed

- Next Generation Science Standards: 3-5-ETS1-1
- Common Core State Standards - Mathematics: MP1, MP3

Key Terms

engineering design process, prototype

Lesson Summary

Students are introduced to the engineering design challenge: claw games are rigged, and Galactic Games wants to redesign their game. Students engage in problem scoping as they discuss and identify the design challenge described in a memo from the client. Students also review engineering and the engineering design process and work with their teams to create a team charter. They use this team charter to support their work in teams and to hold each other and themselves accountable throughout the unit.

Background

Teacher Background

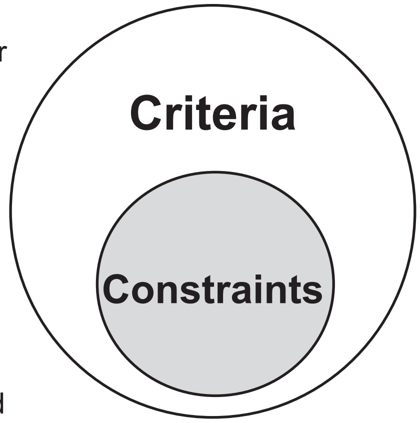
Teamwork: Students should be teamed strategically and may or may not be assigned roles within their team. When forming student teams, consider academic, language, and social needs. In place of strategic teaming, a random teaming can be substituted. Students will work in these teams, or "teams," of three or four throughout the unit. Effective teamwork is essential in this unit as well as in engineering in general; however, this unit does not provide specific support to develop those skills. If students do not have experience with teamwork, targeted team-building activities are highly recommended prior to beginning this unit.

Engineering Design Process: Students should have some familiarity with the engineering design process before beginning the unit. If they do not, the teacher will need to spend additional time explaining it, so this lesson may take more than one day. The engineering design process (EDP) is an iterative, systematic process used to guide the development of solutions to engineering problems. There is no single engineering design process, just like there is not one scientific method. However, the various engineering design processes have similar components. The engineering design process (EDP) is an iterative process that involves understanding the problem, learning background information necessary to solve the problem, planning, trying, testing the solution, making changes based on the tests, and communicating their ideas. Students will use a engineering design process slider throughout the unit to help them understand where they are in the design process. For more information about the steps of the engineering design process presented in this unit, see the front matter section about it.

Some common misconceptions about the EDP:

- Engineers do not have to learn anything new when they are working on a project.
    - **In reality:** Engineers need to continually learn throughout their lives.
- The engineering design process is linear, and you never need to go back to previous phases.
    - **In reality:** The EDP is a cyclical process that requires many iterations.
- Once engineers are done with a project, they never think about it again.
    - **In reality:** A project is never really "done," and engineers often continue to improve and make changes.

Criteria and constraints: One difficulty students might have is distinguishing between criteria and constraints. Criteria are the things required for a successful design, or goals of the designed solutions. They help engineers decide whether the solution has solved the problem. Another way of thinking about criteria are that they are anything that the client and the engineers will use to judge the quality of a solution. Constraints are a specific type of criteria; they are those criteria that limit design possibilities, or the ways that the problem can be solved. If constraints are not met, the design solution is by default not a viable solution to the problem. The relationship between criteria and constraints is represented in the figure. It may be helpful to post the definitions with the figure somewhere in the classroom for future reference.



Cost is a common example of something that can be a criterion and a constraint. If the client requires engineers to stay within a specific budget, then this budget is a constraint. Any design solution that requires more money than the budget is automatically disqualified from being a quality solution. However, cost is also a relative criterion. Multiple design solutions that stay within the budget can be proposed. The costs of these solutions could be compared as one factor to determine which of the solutions is preferable.

Problem Scoping: In this lesson, students will be in the Problem Scoping section of the engineering design process, specifically on the define the problem step. Define the problem and learn about the problem combine to make Problem Scoping. In this stage, students will be first introduced to the engineering problem through a client letter and then be given a chance to ask questions to the client to receive more information about the problem. The problem statements given in the client memos purposefully do not provide all the information necessary to solve the problem. Students are tasked with generating questions about the problem to try to fill in this missing information. Based on all information from the client, students will then define the problem in terms of: what the problem is and why it is important, who are the client and end users, what are the criteria and constraints, and what other information they may need to learn about in order to solve the problem. This process of generating ideas and questions for the client is an important skill on its own both in engineering and in other fields, but it also helps to ensure that the students fully understand the problem and their task in the engineering design challenge.

Solution Generation: The Solution Generation section of the engineering design process includes plan the solution, try out the plan of the solution, test the solution, and decide whether the solution is good enough. When engineers are generating solutions, they will use iteration as a means to continually improve their solution, reflect back on the problem definition and what they have learned about the problem, and consider criteria, constraints, and trade-offs. Trade-offs involve having to make compromises about which criteria to emphasize because they compete with one another in terms

Assessments

Pre-Activity Assessment
Pretest covering material on electricity, magnets, and electromagnets.

Activity Embedded Assessment
Monitor students individual responses to and team discussions regarding the *1.e. Problem Scoping* to check for understanding of the problem.

Post-Activity Assessment
Exit slip--Why do claw games need to be redesigned?

Use the *1.f. Problem Scoping Rubric* to provide feedback to students on their responses to *1.e. Problem Scoping.*

DUPLICATION MASTERS

- 1.a. What is Engineering?
- 1.b. Client Memo 1: Claw Games are Rigged
- 1.c. Claw Machines are Rigged Article
- 1.d. Client Memo 1 Part 2
- 1.e. Problem Scoping
- 1.g. Client Memo 1 Part 3

EDUCATOR RESOURCES

- 1.f. Problem Scoping Rubric
- 1.h. Problem Scoping Question Response Template

of making the solution effective. For example, cost could be a trade-off for durability.

Engineering notebook: Throughout the unit students will be recording information in an engineering notebook, and they will need the notebook immediately in Lesson 1. Students' engineering notebooks will support their communication of ideas and should be used consistently throughout the unit. A number of worksheets are provided as duplication masters. If these worksheets are printed for students, they should be taped or stapled into their engineering notebooks so all of the unit information is stored within the notebooks.

Vocabulary: Students will be introduced to many new science and engineering vocabulary terms throughout the unit. It may be helpful to create a vocabulary section in their notebook with term definition and memory clue or picture. Additionally, the class could maintain a word wall.

Engineering & engineering design: This lesson includes discussion about engineers and engineering. This may take more or less time depending on how much prior experience students have with engineering. The unit focuses on electrical engineering, where engineers design tools and machines that let people use electricity to accomplish specific tasks. In this unit, students will be designing an electromagnetic claw-arm for use in an arcade style claw game.

Team charters: In this lesson, you may have students create a team charter. A "team charter" is a document that is developed by each team (collaboratively) to identify how the team will function. The development of a full team charter consists of three main phases: (1) Individual Preparation- where members are asked to detail, in writing, their personal characteristics to introduce themselves to their team; (2) Team Norms, Expectations, and Processes- where members meet and discuss their individual information and determine how they would like to operate and establish their team norms; (3) Rewards and Sanctions- where teams decide how they will monitor themselves and their teammates to ensure that they are living up to the team charter. More information can be found in Mathieu, John E. & Rapp, Tammy L., 2009. Laying the foundation for successful team performance trajectories: The role of team charters and performance strategies. Journal of Applied Psychology, 94(1), 90-103. NOTE: If you choose to have students create team charters, this lesson will likely take more than one class period. Working together to create a class charter could reduce the amount of time, but you may also refer back to the classroom rules and norms that you have already established.

Order of activities: The activities in this lesson may be re-ordered to accommodate your students. For example, it may make sense to move the team charter activity earlier in the lesson, before any problem scoping. Alternatively, it could be moved to the end of the lesson after all problem scoping activities are completed.

Before the Activity

Prior instruction on electricity & magnetism: Students should have already completed units that taught electricity (including basic circuits) and magnetism.

Claw Games are Rigged!: Problem Scoping

This unit will help students review those topics while introducing them to the engineering design process and allowing them to learn how to run a controlled experiment.

Organizing student handouts and written work: Throughout this unit, each team will have a Team Folder, where important documents for the team will be kept (such as team charters and client memos). Each student will have a paper engineering notebook, where students will keep their individual notes and justifications. The engineering notebook allows students to document their thinking and reflect on their learning throughout the design challenge and at the end when developing their final video presentation. If you use science notebooks with your students, you can also use a tab within the science notebook to create a section dedicated to engineering.

Assemble the *Engineering Design Process* sliders and post an EDP poster in the classroom (see the front matter for how to assemble them).

Classroom Instruction

Introduction

1. **Introduce the unit. Say:** *We will be working on an engineering project where you will help an arcade game designer.*

2. **Introduce the engineering design notebooks. Say:** *Engineers use notebooks to document their design process and keep notes. We will also be using engineering notebooks throughout our engineering challenge. Each day, you'll use the notebooks to take notes and record what you are learning. In addition, there are questions that you'll be asked to answer. Sometimes you'll answer the questions first on your own, then in your teams. Each day, turn in your engineering notebooks before you leave class.* NOTE: You can have your students write in their notebooks in two different colors – one for thoughts and prompts that are individual and one for thoughts and prompts that they discuss in their teams. This will help you assess the students' ideas as well as help them recognize their own contributions and ideas. You also may want to have students complete a Notebook Cover and start a Table of Contents page. You may choose to have students tape/glue copies of the notebook prompts and/or the duplication masters into their notebooks.

3. **Complete notebook prompts about engineering.** Have students individually answer the prompts from *1.a. What is Engineering?* in their notebooks prior to teaching them anything else about the unit or about engineering. Tell students it is okay if they do not know very much about engineers or engineering – just have them answer the questions to the best of their ability.Have them write their responses directly in their engineering notebook or on handout *1.a. What is Engineering?*, then discuss their answers with their neighbors. Have students share their responses with the class, and use students' responses to gauge their understanding of engineering and guide the following discussion. Encourage students to record new ideas from their classmates in a different color in their notebooks. If students used handout 1.a., have

them paste it into their notebooks. NOTE: See pages 100-102 for using notebooks rather than duplication masters.

4. **Introduce the engineering design process.** Show the Engineering Design Process poster and distribute the Engineering Design Process sliders to each student. Briefly describe each step. See the front matter for explanations of the steps of the engineering design process.

5. **Introduce the problem and the client.** Explain that the students are going to be working in small teams to solve a problem being brought to them by Galactic Games. Put students into the teams that they will be in throughout the rest of the unit. Have them come up with a team name. Once they have done that, **Ask:** *Have you ever played a "claw game" at an arcade? Have you ever won a toy?* Allow students to share their experiences. **(Optional)** Using a store bought claw game let students try it. Distribute handout *1.b. Client Memo 1: Claw Games are Rigged and 1.c. Claw Games are Rigged Article* and have students read them. Lead a discussion covering the main ideas of the client memo and the article. Be sure to cover the idea that strength of the claw grip is often programmed to prevent players from winning by releasing the toy or by having too weak of a grip.

6. **Identify the client and the problem**. Have students answer questions 1 and 2 on the *1.e. Problem Scoping* handout. Students can answer these directly in their notebooks or you may choose to have students respond directly on the *1.e. Problem Scoping* handout. In this case, make sure to have students include the handout in their notebooks. Students should first resond individually and then should discuss their responses with their teammates. Using two different colored pencils or pens for individual and team responses can help to distinguish them.

7. **Discuss the client and the problem**. As a class, discuss their answers to the first two problem scoping questions. Then give students a chance to identify ways they might be able to help the client with the problem. **Ask**: *How can we help the client with their problem?* Also discuss whether the students think it is fair and if not, what would make a fair game. NOTE: At this point, their ideas do not need to be (and probably will not be) related to electromagnetic claw arms. That is ok and expected. This portion of the problem scoping excercise is meant to get students thinking deeply about the problem and the many ways in which they could approach it.

8. **Introduce the design challenge.** Distribute copies of *1.d. Client Memo 1 Part 2* and direct students to read the memo. NOTE: For ELL students or students who struggle with reading, a graphic organizer or other reading support strategy will be useful for both readings.

9. **Discuss ongoing communication with the client.** Explain that engineers often need to ask questions to help clarify the problem and what they are being asked to do. Initial communications from the client may be missing important information that the client might not have known the engineers would need. Students will need to ask questions of the client to better

understand their task. Throughout the unit, students will continue to communicate with the client on a regular basis to receive more information and provide progress updates.

Activity #1: Problem Scoping Part 1

10. **Generate questions.** Once students have finished reading the second client memo, have them generate questions to ask of the client. Have students answer the prompt from *1.e. Problem Scoping* Section - "Questions for the Client" (prompt 3) in their engineering notebooks (or attach the handout in their notebooks).

11. **Share questions.** Ask students to share their questions. As students share, record these questions so that they are visible for all students to see. Don't write duplicate questions more than once, and continue soliciting questions until no new questions are suggested.

12. **Provide responses to questions.** "The client" should provide answers to these questions. These questions can be answered by the teacher who can act as a spokesperson for the client or via *1.g. Client Memo 1 Part 3*, to which answers to the questions would need to be attached as a second page. Some questions may need to be answered right away, while other questions may be answered at a later date during the unit. Students will likely generate a variety of relevant and less relevant questions. Good problem scoping questions need to be answered to begin solving the problem and help engineers understand the problem better. Less relevant questions will focus more on the context of the problem (e.g. *Are the companies going to get in trouble for having rigged claw games?*). Don't discount these questions, but highlight those that are more relevant and try to help students distinguish between them. Students will probably have many relevant questions, but if they struggle providing them with an example may help. See *1.h. Problem Scoping Question Response Template* for sample questions and strategies for answering the questions. Once students have exhausted their questions, provide answers (or at least responses) to the questions from the client. There are several options for this:
    - **Option 1:** Add answers to handout *1.g. Client Memo 1 Part 3* as an attachment and distribute these to the students. This option works best if there is a break between asking the questions and answering the questions (i.e. if class ends after generating questions and picks up the next day with the answers).
    - **Option 2:** Pretend to call the client and act out one side of the phone conversation where you solicit answers from the client.
    - **Option 3:** Tell the students that you have already talked to the client who has given you more information; therefore you can answer the questions on behalf of the client. Even in this case it might make sense to say that you are going to consult with the client before answering all of the questions.

13. **Identify where they are in the engineering design process. (Define)**
    Ask: *Which phase of the engineering design process are we in right now?*

Say: *We are getting ready to begin learning about the electromagnets we will be designing for the challenge.* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

(Optional) Activity #2: Develop a Team Charter

14. **Introduce team charters. Say:** *To help your team work well in a team, we are going to develop a team charter. This charter is an agreement between all of the team members about your goals and expectations.*

15. **Set team goals.** Have students individually respond to the following prompts in their notebooks:
    - What are your general goals for the project?
    - Who will be responsible for what activity?
    - What is your timetable (when do you expect to have each part finished)?
    - What expectations do you have for the work team members do?
    - Who should contribute ideas to the team?
    - What expectations do you have about the way team members will work together?
    - Is there anything else you want to include?

16. **Create the team charter.** Once students have responded individually to the above prompts, have them work together to combine their answers into a team charter. Explain that the team charter describes team norms and team roles. You may need to explain and give examples of norms and potential roles. If teams have time they can create a team name and a team logo. The team charter should be an "official" document that all students sign and is placed in their engineering folder for reference. It is important that the teacher speaks and models how team members can refer back to the team norms if a team member is not following the established norm. (For example: If a student is interrupting and "respectful listening" is an established team norm, a student could say "Name, please remember that one of our team norms is to listen respectfully to others' ideas because it makes us feel like our ideas are important.")

Activity #3: Problem Scoping Part 2

NOTE: Prior to this, the teacher must print *1.g. Client Memo 1 Part 3* and prepare the attachment with answers to the students' questions (see *1.h. Problem Scoping Question Response Template*) if necessary.

17. **Formulate the problem.** Share *1.g. Client Memo 1 Part 3* the attached answers. Have students read the response from the client. Based on the original client memo and the response memo, have students individually fill out their engineering notebooks with the remaining prompts from *1.e. Problem Scoping* Section - "Problem Scoping Record" (or attach the handout in their notebooks). Once all students have completed the prompts individually, have students discuss their answers with their team. Using a different colored pen or pencil (to distinguish individual from team work), students should add to or change their answers based on the consensus within the team (or write in the team answers section). Make sure that

students indicate in their notebooks which color represents individual and team work.

18. **Discuss as a class.** Call students back together for a whole team discussion. **Ask:** *What is the client's problem?* Because claw games have a reputation for being unfair, they want to redesign their claw game to use an electromagnet instead of a claw. **Ask:** *What is your role in solving the problem?* Learn how to build an electromagnet, design and test the electromagnetic arm, and communicate to the client what our design is and why it is effective. **Ask:** *What questions do you still have about the situation or your role in addressing it?* Answers will vary—you can either answer these questions immediately or record them and include the answers in a later client memo. As students share these answers and/or questions, use markers to record questions on an anchor chart to reference throughout the unit. This will be helpful when you want to remind students of the purpose of the unit. NOTE: The purpose of an anchor chart is to make thinking visible to all in the classroom. Anchor charts are often made with poster paper and markers but could also be written on a whiteboard/chalkboard or created electronically. While the anchor chart can take multiple forms, it should be visible to students throughout the unit. Tell students they will continue to get more information that may help answer their questions over the course of the next several lessons.

19. **Identify where they are in the engineering design process. (Define)** **Ask:** *Which phase of the engineering design process are we in right now?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

Closure

20. **Restate the problem. Ask:** *What is the big problem in our engineering challenge?* Designing an electromagnetic arm that can pick up toys in a game.

21. **Complete an exit slip—Why do claw games need to be redesigned?** Direct students to respond to the following prompt in their engineering notebook: *Why do claw games need to be redesigned? What makes you think that?* Student responses to this prompt will indicate their understanding of the context of the problem. If student responses are not consistent with the specifics of the context and the engineering problem, the topic will need to be re-addressed later.

LESSON 1

Name________________________________ Date___________ Period _____

1.a. What is Engineering?

Answer these questions the best you can.

1. What do engineers do?

2. How do engineers solve problems?

LESSON 1

Name________________________________ Date___________ Period _____

1.a. What is Engineering?

Answer these questions the best you can.

1. What do engineers do?

2. How do engineers solve problems?

26 Diggin' For Fools' Gold FT

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Name________________________________ Date__________ Period _____

1.b. Client Memo 1 Part 1

GALACTIC GAMES

4 Milky Way
Earth, Orbiting the Sun
24365

Dear Engineers,

My company, Galactic Games, has a problem. We design and build arcade games and one of longest and best games is the claw game, Diggin' for Fools' Gold. For some reason, people are losing interest in the game and aren't playing it as much. I've attached a news article about claw games, which explains a little about why. We need to figure out how to get people interested in our game again. Can you help us?

Sincerely,

Orion Nova

Orion Nova
President, Galactic Games

Name________________________________ Date____________ Period _____

1.c. Claw Machines are Rigged Article

Claw machines are rigged — here's why it's so hard to grab that stuffed animal

Updated by Phil Edwards on June 3, 2015, 3:14 p.m. ET @PhilEdwardsInc phil.edwards@vox.com

At some point or another you've probably played one of these claw machines, hoping to score the plush toy of your dreams. But despite your skill at perfectly positioning the claw over the prize and activating it, you've found that the pincers just don't grab tightly enough to pick up a stuffed animal.
It's not your imagination. Those claw machines are rigged. But they're rigged in a surprisingly clever way — and not the way most people suspect.

The claw is programmed to grab tightly only part of the time.

Some people think the claw machine is so hard to win because the stuffed animals are packed so tightly together. But the bigger reason is more insidious than that: the claw machine is programmed to have a strong grip only part of the time.
This isn't a closely kept secret. It's publicly available information, pulled straight from the instruction guides for the biggest claw games out there. Open the manual for Black Tie Toys' Advanced Crane Machine.

The machine's owner can fine-tune the strength of the claw beforehand so that it only has a strong grip a fraction of the time that people play.
The owner can manually adjust the "dropping skill," as well. That means that on a given number of tries, the claw will drop a prize that it's grabbed before it delivers it to you.
The machines also allow the owner to select a desired level of profit and then automatically adjust the claw strength to make sure that players are only winning a limited number of times.

This isn't isolated to one claw machine or one company — this is standard practice industry-wide.
Want to win a prize from the Bling King? The machine's instruction manual shows you'll likely have to play dozens of times. The owner can program beforehand how often the claw's grip is strong or weak.

The big decision for machine owners is how fair or unfair they want to make the game. They could adjust the machine so that the claw only operates on full power one out of every 23 times. That would, in theory, create a profit of around 50 percent. (The machine also has ways to ensure this — if a player wins with a "weak claw," the machine can wait even longer before sending full power to the claw.)
But owners also have to be careful, since no one wants to play a machine that never seems to work. So they might want to accept less profit in the short term by allowing the claw to be stronger more often, thereby giving the machine a better reputation.
For the player, however, there's no way to know in advance how strong or weak a machine is.

Adapted From: Edwards, Phil. "Claw machines are rigged — here's why it's so hard to grab that stuffed animal." Vox. Vox Media Inc, June 3, 2015. Web. .<http://www.vox.com/2015/4/3/8339999/claw-machines-rigged>.

LESSON 1

Name________________________________ Date___________ Period _____

1.d. Client Memo 1 Part 2

GALACTIC GAMES

4 Milky Way
Earth, Orbiting the Sun
24365

Dear Electrical Engineering Team,

As you saw from my previous letter, we at Galactic Games are in a terrible situation. Our claw game, “Diggin’ for Fools’ Gold,” which travels around to various carnivals, parties, stores, and restaurants. However, as that news article says, some claw games are rigged! Players can’t win! Whether or not this is true of our games does not matter. People do not want to play our claw game since they don’t think they will win.

You came up with some great ideas for how to get people to play our game again. We thought about it too, and we have decided that we need a new “claw” so customers will think our game is new and different. We would like to contract you to develop a prototype of an electromagnetic arm that will be used in the game instead of the claw. We will only be replacing the claw in our machines, as the other components are still in working order. We have a team of mechanical engineers that will scale up the prototype you develop and place it in our games.

We need you to develop the electromagnetic arm and also explain to our mechanical engineers how to make the electromagnet. You will need to justify your reasoning because the mechanical engineers are responsible for scaling up your design and need to make sure they get all the pieces in the correct place. It is also important that you remember that we want this game to be fair, but also a game of skill, where customers will win some of the time, but not every time.

You will receive daily memos from our various engineering teams that are working on this project. The memos will instruct you on your daily tasks.

Thank you for your consideration,

Orion Nova

Orion Nova
President, Galactic Games

Name________________________________ Date___________ Period _____

1.e. Problem Scoping (1/2)

Problem Scoping Record

Directions: First, **on your own**, answer each of the following questions beside the "My Response" space. Then, in your teams, each person is to **share** their response and discuss. In the space, "Team Response" **write your revised answer** to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. **Who is the client?**

   My response:

   Team response:

2. **What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.**

   My response:

   Team response:

Questions for the Client

3. **What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.**

Name_______________________________ Date__________ Period _____

1.e. Problem Scoping (2/2)

Problem Scoping Record

4. Who are the end-users?

My response:

Team response:

5. What will make the solution effective (criteria)? Use detailed information you have from the client.

My response:

Team response:

6. What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.

My response:

Team response:

7. Think about the problem of claw games that appear rigged. In terms of using magnets to pick up the toys, what are at least 2 things you need to learn in order to design an electromagnetic claw arm for the claw game? Make sure to consider all important aspects of the problem. Be specific.

My response:

Team response:

Student Name________________________________ Date____________ Period _____

1.f. Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.e.3	What are at least 3 questions that you want to ask the client? Ask questions that will help you understand the problem better. Make sure to ask about all important aspects of the problem.	Ask a variety of relevant questions to better understand problem.	**Asked at least 3 questions** CIRCLE: 0 1 2 3 4+	
			At least 3 questions are relevant to the problem CIRCLE: 0 1 2 3 4+	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	
1.e.1	Who is the client?	Identify the client.	yes no	**Correctly identified the client**
1.e.2	What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.	Explain the problem based on a synthesis of information.	yes no	**Identified problem**
		Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Explained why the problem is important**
			yes no	**Provided rationale from client information**
1.e.4	Who are the end-users?	Identify a specific and relevant end user.	yes no	**Correctly identified at least 1 end user**
1.e.5	What will make your solution effective (criteria)? Use detailed information you have from the client.	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
			yes no	**Connected information from client to criteria**

LESSON 1

Student Name______________________ Date__________ Period _____

1.f. Problem Scoping Rubric

Problem	Question	Learning Objectives	Rubric	
1.e.6	What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
			yes no	**Connected information from client to constraints**
1.e.7	Think about the problem of claw games that appear rigged. In terms of using magnets to pick up the toys, what are at least 2 things you need to learn in order to design an electromagnetic claw arm for the claw game? Make sure to consider all important aspects of the problem. Be specific.	Explain the background knowledge needed to develop a solution.	**Identified at least 2 topics they needed to learn** CIRCLE: 0 1 2 3 +	
			Topics are relevant to the problem CIRCLE: 0 1 2 3 +	
			Considered at least 2 different aspects of the problem CIRCLE: 0 1 2 3 +	

Notes:

Name________________________________ Date___________ Period _____

1.g. Client Memo 1 Part 3

GALACTIC GAMES

4 Milky Way
Earth, Orbiting the Sun
24365

Dear Electrical Engineering Team,

Thank you for your excellent questions. I have prepared answers to most of the questions, and I will attach them to this letter. I have also given your teacher some more information, so you can ask your teacher additional questions as they come up.

As you start to learn about designing electromagnets and begin work on designing our new claw arm, if you have any more questions for me or my team, just give them to your teacher who will pass them along to us.

Sincerely,

Orion Nova

Orion Nova
President, Galactic Games

1.h. Problem Scoping Question Response Template

NOTE: Create a document listing student questions and answers to those questions and distribute it with *1.g. Client Memo 1 Part 3*. Here is an example.

What kind of toys does the magnet need to be able to pick up?

The toys are small plastic animals (ducks, pigs, etc.), bouncy balls, and other small toys.

Asking and answering these questions helps students learn about the problem, but it also helps students to learn to ask good questions. As you go back and forth with the students asking and answering questions, try to help them distinguish good questions from less relevant questions. See below for some examples of important and less relevant questions and how you might respond. Also, be careful not to over-respond to questions. Notice that in the example above, students ask about the *kinds* of toys, and that is the only information the answer provides. Students might also want (or need) to know about the size and weight of the toys, but you would want to encourage them to ask for that information directly before giving it to them.

Important Questions:

Do we need to design the joy stick to move the electromagnetic arm to pick up the toys?

POSSIBLE ANSWER: No, we only need you to replace the claw part on the very end with an electromagnetic "claw." We have another engineering team working on redesigning the controls for the game.

You said you want it to be a game of skill but also that you don't want them to win every time. Can you be more specific about that?

POSSIBLE ANSWER: Sure, the skill is in how carefully and quickly the player can get the toy out. If players are careful and also quick enough we want them to win, but if they move too quickly, we want the toy to sometimes fall off. If the magnet is too strong it will always pick up the toy and they won't need any skill, but if the magnet is too weak they will never be able to get a toy no matter how skilled they are. We want the magnet somewhere in the middle so that it is strong enough to pick up the toy, but also still challenging to get the toy to the drop zone.

How often do you want to the players to win?

POSSIBLE ANSWER: We think the game would be fun but still profitable if average players won about 6 or 7 times out of 10.

What size and/or weight are the toys?

POSSIBLE ANSWER: That is a good question. I don't know specifics off the top of my head, but I will gather that information from our game designers and send it to your teacher when I find it.

Less Relevant Questions: These questions are related to the situation or the context of the problem but not related to solving the specific design challenge. The questions deserve answers, but it should be clear that they go beyond their specific task and don't provide useful information for solving the problem.

Is the person who rigged the old games in trouble?

POSSIBLE ANSWER: This is an important question, but I don't know the answer. Our company's games were never rigged to begin with. If there were people who rigged the games at other companies, I don't know if they will get in trouble. Whether they do or not, we want to redesign our games anyway so that they look and play differently from the games people suspect are rigged.

Can people who played the rigged games get their money back?

POSSIBLE ANSWER: If someone played a game that they know was rigged they should contact the company that made that specific game. Our games have always been fair, so we haven't had to worry about that. We just want to make a new game that is different from the Claw Games that people are suspicious of.

LESSON 2 Magnets & Magnetic Materials

Lesson Objectives

Students will be able to:

- make a claim supported with evidence.
- explain how magnets interact with each other and other materials.
- evaluate their role in an academically minded team.

Time Required

two 50-minute class periods

Materials

Per class:

- Engineering Design Process poster
- (8) bar magnets (north & south poles marked)
- (4) rectangular magnets (unmarked)
- (4) steel paper clips
- (4) steel washers
- (4) bear counters
- (2) ring magnets
- (2) disc magnets
- (2) rectangular magnets (small)
- (2) neodynium magnets (small)
- (2) horseshoe magnets
- assortment of magnetic and non-magnet materials

Per team:

- (4) 3"x5" notecards

Per student:

- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Standards Addressed

- Next Generation Science Standards: 5-PS1-3
- Common Core State Standards - Mathematics: MP2, MP5

Key Terms

magnet, magnetism

Lesson Summary

Before beginning their design challenge, students learn background information on magnets and magnetic materials. This will help them make decisions about the types of materials that are appropriate for their design solution. In this lesson, students work through four stations where they examine different aspects of magnetism. Students 1) test a variety of materials to see which ones are magnetic; 2) determine if all magnets have both north and south poles; 3) examine the effect of size and shape on magnet strength; and 4) determine if magnet fields can pass through other materials. The lesson concludes with students summarizing what they have learned about magnets with claims supported by evidence.

Background

Teacher Background

In the first part of this lesson (2A), students will participate in a Four Corners activity. This requires them to demonstrate their opinion by physically moving to one corner of the classroom. In this activity, they will be responding to statements about magnets. Students may ask why they can't just put a magnet on the toys in the game. The rationale behind NOT giving them magnets as an option are 1) The client can't afford magnets for all the toys, 2) magnets stored next to each other can actually become de-magnetized to the point where the electromagnet would not be able to pick up the toy, and 3) the client is worried that the toys might stick to each other if they are magnetic.

In the second part of this lesson, students will be investigating magnets. You will need to gather as many of the following materials as you can (not all are necessary):

- **Magnetic objects:** paper clips (colored and regular), zinc plated metal washers, hex nuts, and bolts, etc.
- **Non-magnetic objects:** pieces of wood, stainless steel, rubber, aluminum foil, sponge, brass, copper discs or sheets (such as pennies from before 1984)

The most common type of stainless steel has added nickel and a higher chromium content than regular steel, which changes the physical structure and creates a nonmagnetic metal. Be careful not to purchase stainless steel washers that are magnetic. Be careful not to magnetize the stainless steel washers by placing them next to permanent magnets or electromagnets for too long. Paper fasteners should not be "brass" colored because this could introduce misconceptions about brass. Make sure that the brass objects purchased are not yellow-plated zinc.

This lesson includes an optional 5th station which can be used for student teams that finish early. In this station, students balance a neodymium disc magnet on its side. They will notice that it orients in one specific direction no matter how the face it initially. This is due to the Earth's magnetic field. To make this effect more noticeable, affix two identical screws to each circular face of the magnet. Once students have explored that phenomenon have use the other neodymium magnet to rotate or roll the first without touching it.

Magnets & Magnetic Materials

LESSON 2

Before the Activity

- Make copies of the following duplication masters:
  - *2.a. Client Memo 2* (1 per student)
  - *2.b. Magnet Investigation* (1 per student)
  - **(Optional)** *2.c. Odd One Out* (1 per student)
  - **(Optional)** *2.d. EDP Self-Assessment* (1 per student)
- Place one sign in each corner of the classroom: Agree, Disagree, It Depends, Not Sure.
- To prep for the magnet investigation, create a baggie/bucket of the materials that will be tested in the magnet investigation, as follows. The fifth station is optional and can be used for teams that finish early.
  - **Station 1: Do all magnets have two poles?:** pencils, magnets with holes, north/south bar magnet (labeled), broken north/south bar magnet
  - **Station 2: Are all materials attracted to magnets?:** rubber, wood, hex bolts, brass screws, copper, paper clips, tin foil, #6 zinc plated metal washers, #6 stainless steel washers, paper fasteners, sponge, #6 brass washers
  - **Station 3: Are larger magnets stronger than smaller magnets?:** variety of different sizes and strength of magnets (example: small weak magnets, large weak magnets, and small strong magnets, e.g. neodymium)
  - **Station 4: Can magnetism pass through other materials?:** one magnet, zinc washer, plastic piece, wood (table/desk), hand/skin, copper sheet.
  - **(Optional) Station 5: Aligning Magnets:** two neodymium disc magnets, two short screws or nails.

Classroom Instruction (Lesson 2A)

Introduction

1. **Review the engineering problem.** Remind students of the engineering design challenge and ask the students to restate the problem. Connect the engineering problem to the activity in this lesson where students learn about magnets. **Say:** *You are going to build an electromagnet to use in a claw game. Before we do that, we need to investigate magnets and magnetic materials to help you design you electromagnet.*

2. **Introduce/review magnets. Ask:** *What do you know/remember about magnets?* Lead a discussion where students share what they know about magnets and their experiences using them in the past.

3. **Discuss magnetism: Say:** *Magnetism is one of a few fundamental forces in nature.* **Ask:** *What's a force?* (a push or a pull). Have students give some examples, which may include physical pushes or pulls, tension in ropes, gravity, buoyancy, and others. Explain that magnets are objects that can push and pull on other magnets and on some other objects without even touching them. We call this force magnetism. Tell the students they will explore some of the properties of magnets and magnetic materials in this lesson.

Assessments

Pre-Activity Assessment
Discussion on review of magnets

Activity Embedded Assessment
2.b. Magnets Investigation

Post-Activity Assessment
Tag recommendation exit slip, *2.c. Odd One Out*, *2.d. Engineering Design Process Self-assessment* rubric

DUPLICATION MASTERS

- 2.a. Client Memo 2
- 2.b. Magnets Investigation
- **(Optional)** 2.c. Odd One Out
- **(Optional)** 2.d. EDP Self-assessment

Magnets & Magnetic Materials

4. **Read the memo from the client.** Distribute *2.a. Client Memo 2.* Have students read the memo from the client together to learn what the client wants students to work on in this lesson. Discuss the task described in the memo as a class.

5. **Describe the need to find an appropriate material.** Explain that the client is looking for a material to be attached to each prize in the game. Because the game will be using an electromagnetic arm instead of a claw, each prize must have something magnetic attached so it can be attracted to the electromagnetic arm.

6. **Introduce toys to be used in engineering challenge.** Show the students a small toy (use the toys that they will use in the final engineering design challenge). **Ask:** *Do you think we can use a magnet to pick up this toy?* Demonstrate that it does not.

7. **Identify where they are in the engineering design process. (Learn)** **Ask:** *Which step of the engineering design process will you be working on during the lesson?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

Activity

8. **Prepare for the four corners activity.** Distribute *2.b. Magnets Investigation*. Direct students to fill in the first column, making a prediction about each statement and describing their response. Remind them to include a description of their thoughts.

9. **Complete the magnets four corners activity.** When students are finished with the column one of *2.b. Magnets Investigation*, do a four corners activity. Explain that students will be moving to different corners of the classroom to show whether they agree, disagree, think it depends, or are not sure about each of the statements about magnets.
   - Point out each sign in the corner of the classroom so students know where to go.
   - Read the first statement and direct students to move to a corner based on their current thinking.
   - Ask several students to share the thinking that informed their choices.
   - Repeat with the remaining statements.

Closure

10. **Plan the investigation.** Have students get back together in their small teams and complete the second column of *2.b. Magnets Investigation*. They will need to think of ways they could test each statement to determine whether it is true, false, or depends on the situation.

11. **Preview the next activity.** Explain that the following lesson will allow students to test out the statements to find out whether they are true, false, or depend on the situation.

Classroom Instruction (Lesson 2B)

Introduction

1. **Review the lesson objective.** Remind students of their task for the lesson and review *2.a. Client Memo 2*. Ask students to restate the needs of the client and the goal for the day in their own words.

2. **Introduce the magnets investigation stations**. Explain that at each station students should use the materials in the bag to investigate one of the questions from *2.b. Magnets Investigation* with the permanent magnets provided.

3. **Direct students to record their observations.** Tell students to bring their *2.b. Magnets Investigation* and a different color writing utensil so they can revise their thoughts about each statement based on their findings at the station. They should indicate the correct answer and fill in the column "I now know because…". Be sure to remind students that they need to use evidence from their investigation.

Activity

4. **Complete the magnet investigation stations.** Students should complete each of the four Magnets Investigation stations. As students work at the stations, circulate around the classroom and ask students what they are learning at each station. Encourage students to provide evidence for their statements based on what they have done at the stations. If teams finish a station early or finish all stations early have them explore the optional 5th station. (See teacher background.)

5. **Discuss as a class.** As a whole class, discuss what students discovered at each station.

6. **Write claims about magnets.** Have students write claims supported by evidence about each station in their engineering notebooks. Explain that you will share what the students have learned with Galactic Games. You may want to provide sentence stems to help the students get started.
   - **Ask:** *What do you think a claim is?* Have them share with the large team -- then record a definition for claim in their engineering notebooks.
   - **Ask:** *What do you need to go with a claim to support it?* Give them an example of an outrageous claim, such as "the sky is purple," and guide them to wanting evidence or proof that the claim is true -- then write a definition of evidence in their notebooks. An example definition might be "observations, pictures, data, and graphs that can be used to support a claim."
   - **Ask:** *What do you think your data shows you?* Explain that this is their claim.
   - **Ask:** *How do you know that's true?* Explain that this is their evidence and justification. Their claims and evidence can be recorded in a T-chart (claims on the left and evidence on the right). Beneath the T-chart, students should write a "justification" sentence or two which connects the evidence to the claim.

Magnets & Magnetic Materials

NOTE: You may ask students to provide evidence first based on what they notice in their data table. Once they have found evidence, ask them what the data means to help them make a generalizable claim.

Closure

7. **(Optional) Complete odd one out.** Distribute the handout *2.c. Odd One Out* and explain that students will determine which of the objects in the list doesn't belong and explain why. Give students time to complete the handout.

8. **Complete an exit slip - recommendation to the client.** On a notecard, have students recommend which material the client should use as the "tag" for the toys in the game and explain why that materials is the best of the available options.

9. **(Optional) Complete the self-assessment.** If time allows, direct students to complete the *2.d. EDP Self-Assessment* rubric.

10. **(Optional) Revisit the four corners activity.** Repeat the four corners activity from before based on what the students learned at each station.

Magnets & Magnetic Materials

LESSON 2

LESSON 2

Name________________________________ Date___________ Period _____

2.a. Client Memo 2

GALACTIC GAMES
4 Milky Way
Earth, Orbiting the Sun
24365

Memo

To: engr.teams@myschool.org

From: apollo.eos@galacticgames.com,

CC: halley.comet@galacticgames.com, luna.titania@galacticgames.com, orion.nova@galacticgames.com

Re: Magnets

Hello Engineering Teams,

Our toy design team has been working on designing the toys that will be found inside the new version of the claw game. They realized that most toys won't work with the electromagnets that you are designing. They plan to attach some material that is attracted to magnets to each toy so that the electromagnetic claw will work. They need your teams to help determine which material will work best with a magnetic arm. We have provided each team with a bag of materials. Test to see which ones are attracted to a magnet and provide a report on which material should be used for the final toy design.

Thanks,

Apollo

LESSON 2

Name________________________________ Date___________ Period _____

2.b. Magnets Investigation

Prediction	**Before:** How can you find out?	**After:** I now know because...
1. All magnets have 2 poles. ___Agree ___Disagree ___It depends ___Not sure My Thoughts:		
2. All metals are attracted to magnets. ___Agree ___Disagree ___It depends ___Not sure My Thoughts:		
3. Larger magnets are stronger than smaller magnets. ___Agree ___Disagree ___It depends ___Not sure My Thoughts:		
4. Magnetism can pass through other materials. ___Agree ___Disagree ___It depends ___Not sure My Thoughts:		

LESSON 2

Name________________________________ Date___________ Period _____

2.c. Odd One Out

Which is the odd one out? ***(circle the material that doesn't belong with the others)***	**Why is it the odd one out?**
rubber sponge wood hex bolt stainless steel washer	
aluminum foil penny (copper) brass screw paper clip	

LESSON 2

Name________________________________ Date___________ Period _____

2.c. Odd One Out

Which is the odd one out? ***(circle the material that doesn't belong with the others)***	**Why is it the odd one out?**
rubber sponge wood hex bolt stainless steel washer	
aluminum foil penny (copper) brass screw paper clip	

44 Diggin' For Fools' Gold FT
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LESSON 2

Name____ Date____________ Period _____

2.d. EDP Self-Assessment

1. Which step or steps of the engineering design process did your team work on today? *(Circle all that apply.)* **Define** **Learn** **Plan** **Try** **Test** **Decide**

2. My participation: *(choose one answer)*
   ___ I let my team do all of the work.
   ___ I helped my team a little bit.
   ___ I did what I was supposed to do today.
   ___ I did more than I was supposed to do.

3. Why did you choose that answer *(in number 2)*?

4. One thing I did well today is:

5. One thing I need to work on is:

LESSON 2

Name____ Date____________ Period _____

2.d. EDP Self-Assessment

1. Which step or steps of the engineering design process did your team work on today? *(Circle all that apply.)* **Define** **Learn** **Plan** **Try** **Test** **Decide**

2. My participation: *(choose one answer)*
   ___ I let my team do all of the work.
   ___ I helped my team a little bit.
   ___ I did what I was supposed to do today.
   ___ I did more than I was supposed to do.

3. Why did you choose that answer *(in number 2)*?

4. One thing I did well today is:

5. One thing I need to work on is:

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Diggin' For Fools' Gold FT 45

LESSON 3

Electromagnet Exploration/Variable Sort

Lesson Objectives
Students will be able to:
- describe how electromagnets work.
- identify possible ways to change electromagnetic strength.

Time Required
one 50-minute class period

Materials
Per class:
- Engineering Design Process poster

Per team:
- 10 ft copper wire (insulated, 20 gauge)
- (1) 3-1/2 in. steel nail
- (2) alligator clips
- (100) hex nuts (size 6-32 machine screws)
- (2) D batteries
- (2) D battery holders
- 2 in. copper wire (bare, 20 gauge)

Per student:
- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Standards Addressed
- Next Generation Science Standards: 3-5-ETS1-1, 3-5-ETS1-3, MS-PS2-3, MS-ETS1-1, MS-ETS1-2
- Common Core State Standards - Mathematics: MP3, MP5

Key Terms
electromagnet, dependent variable, independent variable

Lesson Summary
In this lesson, students investigate different aspects of electromagnets that impact the way magnets works. Students explore how they can use an electromagnet to pick up magnetic materials in order to determine different ways the electromagnet can be modified. This will allow them to develop a list of specific variables that they feel might impact the strength or performance of the electromagnet. Once they have generated this list, they discuss how they might test each variable. In the next lesson, they will actually begin to test one of these variables.

Background
Teacher Background
An electromagnet is a device that uses electricity to create a magnetic field that can act as a magnet. Electromagnets are created by running a current through a coil of wire. When the current passes through the coil, the magnet field generated by the current builds on itself is focused in one direction along the length of the coil. The strength of an electromagnet depends on the current through the wire, the number of turns in the coil, and the material of inside the coil (called the core). Other factors also contribute, but not as significantly. The current in the wire is determined by the battery voltage and the resistance in the wire. Higher voltages produce higher currents, but higher currents can be dangerous, so it is recommended to only use 1.5 V batteries (size AA, C, or D). You can increase the voltage by using two or three batteries in series. Additionally, the current is effected by the resistance in the circuit. Less resistance means more current. Resistance in an electromagnet comes from two places: the battery itself has internal resistance, and the wire has resistance. Thicker and shorter wires have less resistance. Wire thickness is measured by gauge or AWG. As the number of the gauge increases, the diameter of the wire decreases (i.e. 20-gauge or 20 AWG wire is thicker than 24-gauge or 24 AWG wire). Additionally, the alligator clips used to connect the circuit add resistance, thus when connecting batteries in series it is recommended to use short pieces of thick copper wire rather than alligator clips. Wire used for electromagnets needs to either be insulated or enamel-coated with the ends sanded or stripped down, otherwise the current will not pass through the coil.

For this lesson, each team should get the same electromagnet set-up to explore. The focus of this lesson is to observe the electromagnet in action and to come up with a list of variables that could be changed in the electromagnets, rather than learning how to make an electromagnet. One alligator clip in this lesson refers to two clips connected by a wire. Each team will need two of these.

SAFETY CONCERN #1: The batteries and wires will get hot if left connected. Make sure that students disconnect at least one of the alligator clips from the battery when they are not testing it. The battery should only be connected with both clips for a few seconds at a time for each test.

SAFETY CONCERN #2: When students connect multiple batteries together, they must be connected in series (not parallel), otherwise they will smoke.

Electromagnet Exploration/Variable Sort

LESSON 3

Batteries are connected in series when they are connected end to end (+ to -) in one path or loop. Batteries are connected in parallel when the path splits and each battery is part of its own loop.

Critical Response Protocol: Protocols are a great way to provide equity in the classroom by allowing all students the chance to be heard, no matter their previous knowledge about the given object or picture. Protocols require a picture or object that provides enough detail for students to observe for at least 10 minutes, ideally 15 minutes. The protocol can be completed verbally or in writing. It can be helpful to have students write their own answers first (give them 3-5 minutes) then start sharing out. If students know, or think they know, about the object being investigated, encourage them to write down their thought but not to share them immediately, out of fairness to others. The protocol is listed below.

Getting Started

- Facilitator: Introduces protocol by having students divide their paper (a page in the engineering notebook) into the sections below.

What do you notice? (I notice…)

- Facilitator: Ask the team to describe what they see/hear without judgment. If judgment emerges, ask for evidence on which the judgment is based: what do you see that makes you say that?
- Students: Answer the question using descriptive terms, without making judgments about the quality of the work or offering personal preferences: "I noticed that…"

What does it remind you of? (I'm reminded of…)

- Facilitator: Ask the team to consider how they connect this work to their life: what memory or experience does it evoke?
- Students: Respond with any memory, experience, story, music or other ideas that this example triggers. No wrong answers.

How do you feel? (I'm feeling…)

- Facilitator: Ask the team to share what feelings the work evokes and to describe their feelings in one or two words.
- Students: Respond honestly. There are no wrong answers.

What questions does it raise? (I'm wondering…)

- Facilitator: Ask the team what questions the work triggers.
- Students: Raise any questions about the work: I wonder….

Speculate (I speculate…. or The big idea is….)

- Facilitator: Ask the team to speculate about what the work helps them to understand. What was the artist's/author's intent? What might be a "Big Idea" that the makers of this want us to understand?
- Students: Respond with the meaning you take away.

Before the Activity

- Make sure that the batteries are completely charged. Electromagnets use up batteries faster than many other applications so the batteries will need to be replaced frequently.
- Cut one wire (10 feet in length) for each team. Be sure to either strip or sand down a half inch on each end of the wire to expose the copper inside to make a good connection in the circuit. You may choose to assemble the

Assessments

Pre-Activity Assessment
Responses to "*What step of the design process are you in?*"

Activity Embedded Assessment
Discussions on what variables to test and how to test them will indicate the students' general understanding of magnets at this point.

Post-Activity Assessment
3.c. Concept Cartoon

DUPLICATION MASTERS

- 3.a. Client Memo 3
- 3.c. Concept Cartoon

EDUCATOR RESOURCES

- 3.b. Critical Response Protocol Image

magnets before class, but having students assemble them will give them a better experience with the electromagnets. If you choose to pre-assemble them, coil the wire around the nail at least 50 times, leaving two inches of wire hanging off the nail at the beginning, and at least another two inches of wire at the other end for connecting the circuit.

- Create baggies/buckets that includes the alligator clips, battery, hex nuts, and nails with wire to distribute to student pairs/teams. This baggie can be given out in following lessons and will be referred to as an “electromagnetic set.”
- Make copies of the following duplication masters:
    - *3.a. Client Memo 3* (1 per student)

Classroom Instruction

Introduction

1. **Read the client memo.** Have students read *3.a. Client Memo 3* and review which step of the engineering design process they will be working on during the lesson.

2. **Identify where they are in the engineering design process. (Learn)Ask:** *Which step of the engineering design process will you be working on during the lesson?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

3. **Complete the critical response protocol.** Show students a picture of a completed electromagnet, as shown on the *3.b. Critical Response Protocol Image*. Complete an abbreviated version of the critical response protocol (see teacher background section for details. Discuss the following prompts with students: *What do you notice? What does it remind you of? What does it make you feel? What do you wonder?*

Activity

4. **Explore electromagnets.** Provide students with electromagnet sets and demonstrate how to assemble the electromagnet and how to use the alligator clips to connect and “turn on” the magnet. Allow students time (approximately 5 minutes) to try picking up paper clips and washers with the electromagnet. **SAFETY CONCERN:** Warn students that the batteries, wire, and nails can get hot. Instruct them to always disconnect the battery after each test. *Do not leave the batteries connected for more than a few seconds at a time.*

5. **Create a list of variables. Say:** *We need to figure out how to make our electromagnets stronger or weaker.* **Ask:** *What things do you think we might change about the electromagnet that might make it work differently?* Have students work individually at first and then in their teams to create a list of all the things they could change about their electromagnet. Have students record their individual and team ideas in two separate colors in their engineering notebooks.

Electromagnet Exploration/Variable Sort

6. **Discuss possible variables.** As a class, create a list of the different things/parts you can change. Display this list so all students can see it. Include all ideas at this point.

7. **Discuss how to test the variables.** Decide as a class which variables they could test. Go through the list of variables one by one and ask them how they might test the way each variable changes the way the electromagnet works. If potential variables are not testable or would be very difficult to test in the classroom, remove them from the list. If the list is initially very long, try to reduce the list to a manageable number by eliminating any that won't actually impact the electromagnet. Make sure the list includes (at least) number of coils, size of core, material of core, type of battery, and thickness of wire. When crossing variables off the class list, be sure to let students know that their ideas are not being crossed off because they are bad ideas, but just ones the class can't test because of limited materials. Even variables which are known to not be important or not impact the electromagnet should be considered. It may not be apparent to the students that these variables will not affect the results. If these variables are eliminated from consideration, they should be eliminated because of "limited materials," not because they are unimportant. For the best results, the final list should have at least 4-6 variables for students to test in lesson 5.

8. **Describe variables in experiments.** Explain that the things that change in an experiment are called variables. Connect this to the list they just created. Discuss how one variable can affect another. In this case, for example, the number of coils might affect the number of paper clips the magnet can hold. **(Optional)** Introduce the terms *independent* and *dependent* variable, if appropriate for the level of the students.

Closure

9. **Complete a concept cartoon.** Show students the *3.c. Concept Cartoon* on electromagnets. On a scratch piece of paper or in their notebooks, have them answer the questions found at the bottom of the cartoon.

LESSON 3

Name______________________________ Date___________ Period _____

3.a. Client Memo 3

GALACTIC GAMES
4 Milky Way
Earth, Orbiting the Sun
24365

Memo

To: engr.teams@myschool.org

From: apollo.eos@galacticgames.com,

CC: luna.titania@galacticgames.com, halley.comet@galacticgames.com, orion.nova@galacticgames.com

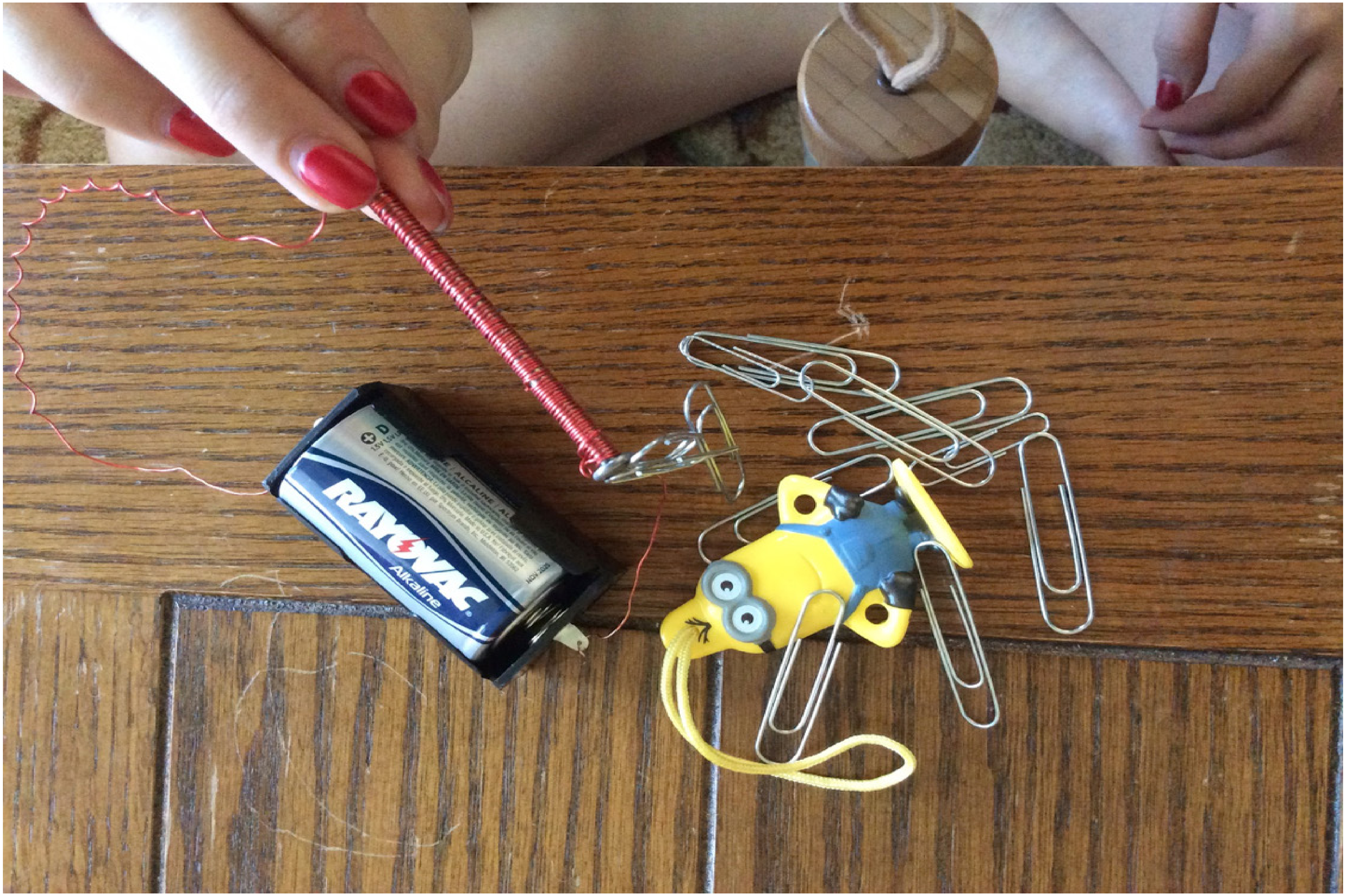
Re: Electromagnet Investigation

Thanks for the great recommendations yesterday. Our toy design teams will use the materials you recommended to make the “tags” for the toys in the Diggin’ for Fools’ Gold game. Great work!

Today we will need you to begin to investigate electromagnets. You’ll need to know how they work before you can begin your designs. We’d also like to know what variables in an electromagnetic can be changed to change the way it works. We’ve sent along a simple electromagnet for you to use in order to complete this task.

Apollo

3.b. Critical Response Protocol Image

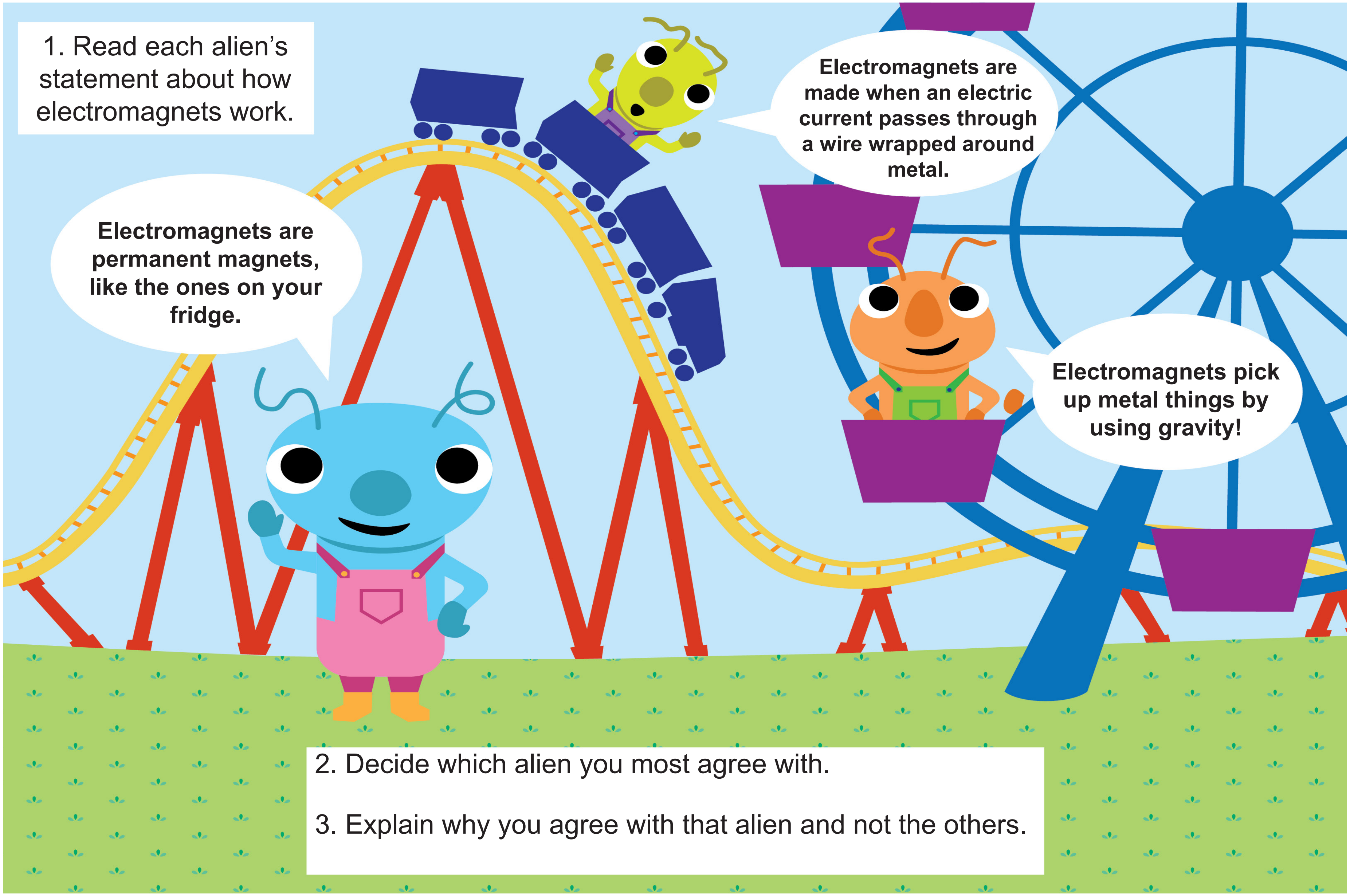


LESSON 3

Name______________________ Date____________ Period _____

3.c. Concept Cartoon

1. Read each alien's statement about how electromagnets work.



2. Decide which alien you most agree with.

3. Explain why you agree with that alien and not the others.

LESSON

4 Testing the Number of Coils

Lesson Objectives

Students will be able to:

- identify ways to change electromagnetic strength.
- identify the different variables in an experiment.
- create a data table with labels.
- create a claim, supported with evidence.

Time Required

two-three 50-minute class periods

Materials

Per class:

- Engineering Design Process poster

Per team:

- 10 ft copper wire (insulated, 20 gauge)
- (1) 3-1/2 in. steel nail
- (2) alligator clips
- (100) hex nuts (size 6-32 machine screws)
- (2) D batteries
- (2) D battery holders
- 2 in. copper wire (bare, 20 gauge)

Per student:

- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Standards Addressed

- Next Generation Science Standards: 3-5-ETS1-2, 3-5-ETS1-3, MS-PS2-3, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards - Mathematics: 4.MP.B.4, MP4, MP6, 6.SP.B.5.A, 5.MD.B.2

Key Terms

interval, best fit line, scatterplot, claim, evidence

Lesson Summary

One of the variables that students identify as possibly impacting the strength or performance of the electromagnet is the number of coils on the nail. In this lesson, students carry out an experiment to test this variable. Using several different numbers of coils, students collect data on how many small hex nuts the electromagnet can pick up. With this data, the class generates a scatterplot showing the number of hex nuts versus the number of coils. Students examine the data both graphically and tabularly to try to identify how the number of coils impacts the strength of the electromagnet. The lesson concludes with the students writing claims supported with evidence about the effect of coils on electromagnets.

Background

Teacher Background

Background on wire: As the number of the gauge increases, the diameter of the wire decreases (i.e. 20-gauge wire is thicker than 24-gauge wire). Wire used for electromagnets needs to either be insulated or enamel-coated and stripped or sanded at the end.

Summarizing data: When multiple trials are carried out, it is common to combine them to find one summary value. This can be done in a variety of ways, but the mean (average) is the most common. At this level, however, students may not be familiar with the mean (average), so alternative summaries may be more appropriate. For example, the median (middle) value is easier to calculate and is less susceptible to outliers which may arise from experimental error. Students can also simply total the values from their trials to obtain a “total score” for each set-up. As long as the number of trials is consistent, the “total score” approach is equivalent to finding an average but is much simpler to calculate and should be easier for the students to understand. As another option, students can forgo finding a summary value altogether. In this experiment, the data set is small enough that students should be able to look for patterns and trends across all trials without needing to find a summary value. Students will find their own ways to talk about “summaries” of the data, i.e. “most of the time.”

Comparing team data: In this lesson, all teams carry out the same experiment, so their data should be fairly similar. Students should be encouraged to examine their own data for patterns and trends, but when discussing the data as a class, try to focus on data from all teams as one combined class set of data rather than as different sets of data from each team. A common struggle for students when doing data analysis tasks like this is to misinterpret natural variation in the data with “mistakes” or “right and wrong” answers. For example, if two teams do not have the same data and students compare those data sets, students often think that one of the teams has the correct data while the other team is “wrong.” What is more likely is that both teams’ data are “correct” in the sense that they reflect what the students measured, but that the differences arise from uncertainty in the measurement and natural variation in the data. These topics can be challenging for students to understand, but viewing the class data as one combined data set rather than as many different data sets can help students to see that all the data values from all teams represent the same phenomenon.

Lines of best fit: This will most likely be the first time students encounter the idea of lines of best fit, and they will not be expected to master the topic until later in middle school. In this lesson, the line of best fit should be treated informally and intuitively with the focus on using the line to help see patterns and make predictions. Plot.ly is a web based graphing program that can be used on computers or tablets. It can be found at: https://plot.ly/. Teachers must have created accounts for their class before the lesson. One option is to create one class account and give students the username and password, instead of having students create their own account. Other alternatives are possible but will likely require more time. Be sure to provide students with individual paper copies of the plots.

Before the Activity

- Be sure that the batteries are completely charged. Electromagnets use up batteries faster than many other applications.
- Cut one 20-gauge wire (10 feet in length) for each team. Be sure to either strip or sand down a half inch on each end of the wire to expose the copper inside to make a good connection in the circuit. Coil the wire around the nail 10 times, leaving about two inches of wire hanging off the nail at the beginning, and the remaining wire hanging off the other end for connecting the circuit. Students should always use the entire wire, even if there is extra, to avoid introducing an uncontrolled variable (length of the wire) into the experiment.
- Make copies of the following duplication masters:
  - *4.a. Client Memo 4* (1 per student)
  - *4.b. Talking Probe* (1 per student).

SAFETY CONCERN #1: The battery and wires will get hot if left connected. Make sure that students disconnect at least one of the alligator clips from the battery when not testing it. The battery should only be connected with both clips for a few seconds at a time for each test.

SAFETY CONCERN #2: When students connect multiple batteries together, they must be connected in series (not parallel), otherwise they will smoke. Batteries are connected in series when they are connected end to end (+ to -) in one path or loop. Batteries are connected in parallel when the path splits and each battery is part of its own loop.

Classroom Instruction

Introduction

1. **Read the client memo.** Share *4.a. Client Memo 4* with the students. Discuss the memo as a class and describe the goal for the lesson.

2. **Identify where they are in the engineering design process. (Learn)** **Ask:** *Which step of the engineering design process will you be working on during the lesson?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

Assessments

Pre-Activity Assessment
Responses to "*What step of the design process are you in.*"

Activity Embedded Assessment
Writing claims with evidence.

Post-Activity Assessment
Electromagnet claims and *4.b. Talking Probe*.

DUPLICATION MASTERS

- 4.a. Client Memo 4
- 4.b. Talking Probe

LESSON 4

Testing the Number of Coils

Activity

3. **Discuss fair tests. Ask:** *What makes a test fair?* Lead students in a discussion of how to make a fair test.

4. **Describe controlled experiments.** Introduce the term "controlled experiment" to the students and explain that this is what they will do to test the way the number of coils affects the strength of the electromagnet.

5. **Plan the experiment.** In teams, have students discuss how they could conduct an experiment to test the way the number of coils impacts the strength of the electromagnet. Have them record their ideas in their engineering notebooks. Once teams have had a chance to come up with their own ideas, have teams share some of their ideas. Help the class to agree on one plan for testing this variable. Make sure that the plan includes (at least):
   - How they will measure the strength of the magnets.
     - Counting the number of hex nuts picked up is a good way, although others are possible.
     - If size 6-32 hex nuts are not being used, be sure to use something small and light like paper clips. This will allow the magnet to pick up more of the given object and will make the data analysis easier.
   - Testing at least 4 different numbers of coils (ideally more).
     - Make sure there is a broad enough range (e.g., 20 to 100 coils).
   - Repeating each number of coils several times. Keeping all other variables the same (controls).
   - Planning how to compare data after they have collected it. (Some options are listed below. See the teacher background for more information.)
     - Students can compare all trials for all numbers of coils to compare. The data set is small enough that this will still be manageable for the students.
     - Students can add the trials together and compare the totals. This is similar to averaging, but slightly simpler.
     - Students can find the average of all the trials for each number of coils and compare the averages.
     - If averaging or totaling, be sure to discuss why this can be helpful.

6. **Design the data table.** Help students plan what their data table should look like. An example of what the table might look like is shown below. Other layouts are possible. Try to solicit as many of the ideas for the table from the students as possible. Once the class has agreed upon a design for the table, have students draw it in their notebooks.

Number of Coils	Trial 1	Trial 2	Trial 3	Trial 4
______ Coils				
______ Coils				
______ Coils				
______ Coils				

7. **Conduct the experiment.** Distribute the materials in the electromagnet sets. In their teams, have students conduct the experiment, filling in their data table. One data table per team is sufficient, but students may copy the table into each of their individual notebooks.

8. **Examine the data in the table.** Once students start to finish collecting their data, have them examine the table to look for trends or patterns. **Ask:** *What do you notice about the number of coils and the number of hex nuts?* Have them record what they notice in their notebooks. If students struggle to identify relevant patterns or trends, you may want to ask follow-up questions such as: *When did the magnet pick up the most? When did it pick up the least?* etc.

9. **Discuss scatterplots.** Explain that there are other ways of representing data that sometimes make it easier to see patterns. One way is with a scatterplot. Show or draw an example of a scatterplot on the board and explain to students how they can be used to represent data, where one variable (the independent variable) affects the other (the dependent variable). Explain to students that all of the data will be collected to create a class scatterplot. Examining class data (rather than individual team data) should make the general trend more apparent. Additionally, comparing individual team data between teams can lead to misconceptions and is discouraged (see the teacher background for more information. Encourage students to think of all the data from the entire class as one big experiment investigating the relationship between number of coils and magnet strength.

10. **Create a class scatterplot.** There are a few options on how to create the scatterplot depending on the materials you have available:
    - **Option 1:** If computers or iPads are not available, demonstrate how to create a scatterplot with the number of coils on the x-axis and the number of items picked up on the y-axis. Make the scatterplot very large either using an overhead projector or on the board. Have a member of each team add their data to the plot to create one large class data set. Having each team add only one value for each number of coils, e.g. their summary value or just the middle (median) value, can simplify the visual slightly without losing much information.
    - **Option 2:** If computers or iPads are available, use a spreadsheet program (like plot.ly) to generate the scatterplot as described in Option 1. Have students enter data into one class spreadsheet. Create a scatterplot graph of the entire class data using the software. Display the class graph.

    Make a copy of the class graph and distribute one to each student.

11. **Examine the scatterplot. Ask:** *When we display the data like this, what patterns or trends do you see?* Have students describe any patterns they see in their notebooks. The class data should show a roughly linear positive trend of increasing number of hex nuts (or other items) with increasing number of coils. Have some students share the patterns they saw. If no one notices the upward sloping trend, draw their attention to it.

Testing the Number of Coils

12. **Connect to the experiment.** Help students to connect the upward sloping trend in the graph with what they noticed about the number of hex nuts (or other items) lifted with the different numbers of coils. This connection may not be obvious at first because students may have had little experience with this type of graph, but this provides a good opportunity to learn how to interpret these graphs. Here are some suggested questions that highlight this connection:
    - What did you notice about electromagnets with more coils?
    - Where on the scatterplot are the dots with more coils?
    - What did you notice about electromagnets with fewer coils?
    - Where on the scatterplot are the dots with fewer coils?
    - What does it mean that this dot (pick one with many hex nuts) is higher than this one (pick another with fewer hex nuts)?
    - If we added even more coils, what do you think would happen? Where would those data points end up on the scatterplot?

13. **Add a line of best fit.** Again, draw students' attention to the linear trend in the graph. Explain that a line of best fit can help make patterns in graphs more clear. Have students sketch a "best fit" line on the graph. Do not worry about creating an actual line of best fit (i.e. least squares regression line), but instead focus on drawing a line which visually appears to fit the data well. Students' lines will not all be the same, and this is ok. This is an informal introduction to lines of best fit. Here are some tips for helping students draw a good line of best fit:
    - The line should be one single, straight line.
    - The line does not have to go through any of the points.
    - There should be roughly equal numbers of dots above and below the line.
    - (In this case) the line should go through the origin.

14. **Make predictions.** Individually in their notebooks, have students make predictions about the number of hex nuts (or other items) that would be picked up for numbers of coils not tested (for example, 50 coils, 70 coils, 110 coils). Encourage them to use the best fit line to help them make a prediction. This should be done by visually viewing the graph, not using an equation. Discuss these predictions as a class. Specifically, **ask:** *how many hex nuts would you expect the electromagnet to pick up if it had 70 coils? Where on the scatterplot would you find an electromagnet with 70 coils? How high up is the line at that point? Etc.*

15. **Write a claim with evidence.** Have students write claims supported by evidence about the relationship between the number of coils and the strength of the magnets. You may want to provide sentence stems to help the students get started. For example, "When we add more coils to the electromagnet _________________. The evidence that makes me think this is __________________." Explain to the students that their claims and evidence will be shared with the client.

Closure

16. **Look at example claims and evidence.** Distribute *4.b. Talking Probe* to students and provide time for students to complete the talking probe about claims and evidence. NOTE: You may have students complete one or both talking probes depending on the amount of available time.

LESSON 4

Name_______________________________ Date___________ Period _____

4.a. Client Memo 4

GALACTIC GAMES

4 Milky Way
Earth, Orbiting the Sun
24365

Memo

To: engr.teams@myschool.org

From: orion.nova@galacticgames.com
CC: luna.titania@galacticgames.com, apollo.eos@galacticgames.com, halley.comet@galacticgames.com

Re: Electromagnet Experiments

Your teacher shared with us the list of variables you came up with yesterday, and we were impressed by your work. We would like you to continue by testing how the number of coils affects the strength of the electromagnet. You should design a controlled experiment to conduct this test. We think that of all the variables you have listed, testing the number of coils could be the most valuable data for your research. We will need you to collect data and report back your findings in 2-3 sentences.

Orion

LESSON 4

Name________________________________ Date__________ Period _____

4.b. Talking Probe

Electromagnet Claims & Evidence

Kaj, Isabella, and Jerry are talking about their experiment on electromagnets.

Kaj says, "I claim that adding more batteries makes the electromagnet stronger because I saw it."

Isabella responded, "I claim that when you add more batteries, the electromagnet is stronger because one battery made the electromagnet pick up 10 hex nuts and two batteries made the electromagnet pick up 25 hex nuts."

Jerry exclaims, "I claim that electromagnets are not made stronger by adding more batteries. I also claim that I want ice cream because I am really hot and tired. I also love Dairy Queen…and bananas…and the moon."

Which student had the best claim and evidence for the experiment? Describe your thinking.

Interpreting Data

Kaj, Isabella, and Jerry are talking about their experiment on electromagnets. Their data is below.

Kaj says, "The electromagnet with fewer coils picked up fewer hex nuts. The electromagnet with more coils picked up more hex nuts."

Isabella responded, "Changing the number of coils changes the number of hex nuts that get picked up."

Jerry exclaims, "The electromagnet-thingy picks up a lot of hex nuts with fewer coils! It's like magic!

Data

Number of Coils	Trial 1	Trial 2	Trial 3	Trial 4
10 Coils	2 hex nuts	0 hex nuts	1 hex nuts	3 hex nuts
30 Coils	10 hex nuts	7 hex nuts	13 hex nuts	30 hex nuts
55 Coils	25 hex nuts	30 hex nuts	35 hex nuts	90 hex nuts
80 Coils	45 hex nuts	38 hex nuts	42 hex nuts	125 hex nuts

Which student had the best interpretation of the data for the experiment? Explain why you think that student had the best claim and evidence.

LESSON 5 Electromagnet Team Experiments

Lesson Objectives

Students will be able to:

- experiment with electromagnets to collect data that will inform decisions for solutions/designs in the engineering design challenge.
- create a data table with labels.
- create a graph of data with labels.
- identify patterns in data.
- evaluate their role in an academically minded team.

Time Required

two-three 50-minute class periods

Materials

Per class:

- Engineering Design Process poster
- (4) 10 ft insulated copper wire (18 and 24 gauge)
- (12) alligator clips
- (4) AA batteries
- (4) C batteries
- (8) D batteries
- (4) battery holders (sizes AA, C and D)
- (4) 3-1/2 in. aluminum nails
- (4) 3-1/2 in. galvanized steel nail
- (4) 2-1/2 in. steel nail
- (4) 3 in. steel nail
- (4) 4 in. steel nail
- (4) 4 in. steel finishing nail
- (4) 4 in. steel bolt (thick)
- (4) 3-1/2 in. wooden dowel
- (4) 3-1/2 in. plastic rod

Per team:

- 10 ft insulated copper wire (20 gauge)
- (1) 3-1/2 in. steel nail
- (2) alligator clips
- (100) hex nuts (size 6-32 machine screws)
- (2) D batteries
- (2) battery holders (size D)
- (1) 3-1/2 in. stainless steel nail
- (1) poster or chart paper
- (1) pack of markers

Lesson Summary

In this lesson, teams choose another variable to test. Again, they collect data for several different values of the variable and create tables/visual displays to look for patterns in the data. Students then create a poster to share their experiment and results with the class. These posters contain detail about the experiments as well as claims supported by evidence about the effect of their variable on the strength of the electromagnet.

Background

Teacher Background

SAFETY CONCERN #1: The battery and wires will get hot if left connected. Make sure that students disconnect at least one of the alligator clips from the battery when not testing it. The battery should only be connected with both clips for a few seconds at a time for each test.

SAFETY CONCERN #2: When students connect multiple batteries together, they must be connected in series (not parallel), otherwise they will smoke. Batteries are connected in series when they are connected end to end (+ to -) in one path or loop. Batteries are connected in parallel when the path splits and each battery is part of its own loop.

Try to avoid using alligator clips to connect batteries in series. Pre-cut short pieces of wire (using the thickest gauge wire you have) to use as connections between the battery holders. Multiple alligator clips will add too much resistance to the circuit and diminish the performance of the electromagnetics.

While building the electromagnet, students may have difficulties wrapping the low gauge (thick) wire. You may want to help them get started or even wrap all of the coils yourself.

A gallery walk is a discussion technique that gets students out of their chairs to actively engage in their learning. Gallery walks can be used in a variety of ways. To complete a gallery walk, students visit peer teams for an established amount of time (usually between 1-3 minutes), then switch to the next team, visiting all other teams by the end of the "walk." One student from each team may remain with their own poster/presentation to answer question or all students can "walk" and questions can be saved for the end.

Before the Activity

- Make sure that all batteries are fully charged.
- Organize materials by the variable that will be tested.
- Make copies of the following duplication masters:
  - *2.d. EDP Self-Assessment* (1 per student)
  - *5.a. Client Memo 5* (1 per student)

Classroom Instruction

Introduction

1. **Read the client memo.** Students will read the *5.a. Client Memo 5* and review what they will be working on during the lesson.

Electromagnet Team Experiments

2. **Identify where they are in the engineering design process. (Learn)** **Ask:** *Which step of the engineering design process will you be working on during the lesson?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

3. **Review list of variables.** Review the class list of variables in the *5.a. Client Memo 5.* NOTE: If the class list of variables generated in lesson 3 contains variables not listed in the client memo, you may choose to add them.

Activity

4. **Choose a variable.** Have students discuss with their team which variable they want to test. Each team should pick their top three so that there aren't too many duplicates between teams. Assign teams to a variable based on their picks, but also make sure that as a class several different variables are tested. It works best to limit the number of teams that can test each variable to ensure all variables are tested. Ways to decide which team picks first could be pulling popsicle sticks, guessing a number, etc.

5. **Plan the experiment.** Before beginning the experiment, students should plan how they will test whichever variable they have been assigned. Display the prompts below for all teams to see or distribute them as a handout to be glued into their notebooks. Instruct students to record a response to each prompt for their experiment plan.
   - What variable are you testing?
   - How will you change (vary) that variable?
   - What will you measure? (Most likely they will measure the # of hex nuts lifted)
   - What will you keep the same (control)?

   Once teams have completed their plan, circulate around the room to give feedback and approve teams' plans.

6. **Plan their data table.** After teams have planned their experiment they should create a data table to record their data. The data tables should include the different values of the variable they are going to test as well as places to record the results from each trial (students should use tables from Lesson 4 as an example). Again, once teams have created their data table, circulate around to each team to give feedback and approve their tables.

7. **Make a prediction.** In their notebooks, have students make a prediction of what they think will happen as they change the variable that they are testing.

8. **Carry out the experiment.** Have students complete their electromagnet experiment, completing at least three trials for every value of the variable and recording data in their data table.

9. **Graph the data.** Have students create a graph (scatterplot or bar graph depending on the variable) using pencil and paper or digital technology.

Per student:
- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Standards Addressed
- Next Generation Science Standards: 5-PS1-3, 3-5-ETS1-3, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards - Mathematics: MP3, MP4, MP5, 4.MD.B.4, 5.MD.B.2, 6.SP.B.4, 6.SP.B.5.A, 6.SP.B.5.B

Key Terms
claim, evidence, interval, fair test

Assessments
Pre-Activity Assessment
Responses to "*What step of the design process are we/you in.*"

Activity Embedded Assessment
Student created poster with data and claims.

Post-Activity Assessment
2.d. EDP Self-Assessment

DUPLICATION MASTERS
- 2.d. EDP Self-Assessment
- 5.a. Client Memo 5

Electromagnet Team Experiments

10. Make a claim. Have students record a claim supported by evidence about the affect of the variable they tested on the strength or performance of the electromagnet in their notebooks.

11. Create a poster. Each team will create a poster on chart paper with colorful markers. It should including the following:

- What variable was tested (as poster title)
- A drawing or picture of their set-up
- Data table (copied to the poster from their notebook)
- Graph
- A claim with evidence about what their data shows

Closure

12. Present the posters. Students present their experimental set-up and findings to the class by sharing their poster. Hang the posters up around the room for teams to later refer to when they are working on the engineering design. Each team can share with the whole class, or the poster can be presented via a gallery walk.

13. Complete the engineering design process self-assessment. Have students complete *2.d. EDP Self-Assessment*.

Name________________________________ Date__________ Period _____

5.a. Client Memo 5

GALACTIC GAMES
4 Milky Way
Earth, Orbiting the Sun
24365

Memo

To: engr.teams@myschool.org

From: luna.titania@galacticgames.com

CC: apollo.eos@galacticgames.com, halley.comet@galacticgames.com, orion.nova@galacticgames.com

Re: Electromagnet Experiments

We reviewed the results of your experiment on the number of coils, and based on what you presented from your experiments, we need each team to complete another controlled experiment in order to learn more about the electromagnets. Please select another variable to test from the list below and report back what you learn. Please include a data table and graph in your report.

The variables you listed last time that we would like you to investigate are:
1. the material the wire is wrapped around
2. the thickness (gauge) of the wire
3. the number of batteries
4. the size (voltage) of the battery
5. the number of alligator clips
6. the length of core material
7. the thickness of core material

Thanks,

Luna

LESSON 6 Plan and Try

Lesson Objectives
Students will be able to:
- evaluate their role in an academically minded team.
- use evidence from problem scoping to generate multiple initial ideas for a design solution.

Time Required
one 50-minute class period

Materials
Per class:
- Engineering Design Process poster
- (50) steel washers
- (1) hot glue gun with hot glue
- (10) duck counters
- (24) D batteries
- (24) C batteries
- (24) AA batteries
- (8) 10 ft insulated copper wire (18, 20, and 22 gauge)
- (24) alligator clips
- (24) battery holders (sizes AA, C, and D)
- (8) 3-1/2 in. steel nail
- (8) 3-1/2 in. stainless steel nail
- (8) 3-1/2 in. aluminum nail
- (8) 3-1/2 in. galvanized steel nail
- (8) 2-1/2 in. steel nail
- (8) 3 in. steel nail
- (8) 4 in. steel nail
- (8) 3-1/2 in. steel bolt (thin)
- (8) 3-1/2 in. steel bolt (thick)
- various other materials from Lessons 4 and 5.

Per student:
- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Key Terms
evidence-based reasoning, constraint, criteria, prototype

Lesson Summary
Using the information they learned about magnets and electromagnets in the preceding lessons, students design and build an electromagnetic claw arm prototype for Galactic Games. Students justify their design choices using data and evidence from previous lessons in an Evidence Based Reasoning graphic.

Background
Teacher Background
Evidence-based Reasoning: Evidence-based reasoning (EBR) refers to the engineering practice of providing rationale for design ideas and decisions. It is somewhat similar to scientific argumentation in the sense that it involves using evidence and explanations to support a statement, but it is ultimately different. In EBR, the statement being supported is an engineering design idea or decision, whereas in scientific argumentation it is a claim or conclusion about a natural phenomenon. EBR is used in the context of generating solutions for engineering problems; scientific argumentation is used to answer scientific questions about nature. Science and mathematical principles are important justifications for scientific argumentation and EBR. However, EBR often also includes justifications related to the context, criteria, and constraints of the engineering problem (e.g., cost, user needs, technical feasibility). In this lesson, students will use EBR to think deeply about their proposed design ideas and to justify them with information about the engineering problem and their science and mathematics knowledge.

Students may have difficulties wrapping the low gauge (thick) wire. You may want to help them get started or even wrap all of the coils yourself.

SAFETY CONCERN #1: The battery and wires will get hot if left connected. Make sure that students disconnect at least one of the alligator clips from the battery when not testing it. The battery should only be connected with both clips for a few seconds at a time for each test.

SAFETY CONCERN #2: When students connect multiple batteries together, they must be connected in series (not parallel), otherwise they will smoke. Batteries are connected in series when they are connected end to end (+ to -) in one path or loop. Batteries are connected in parallel when the path splits and each battery is part of its own loop.

Before the Activity
- Prepare the testing station. A testing station in this lesson will consist of two containers (shoe boxes or other small containers) and a toy with a washer attached to it. You should prepare one or two testing stations and place them in an easily accessible part of the room. Hot glue a washer to one of the duck counter toys (or other medium sized toys) for each testing station. You may choose to make one for each team to use as they plan and build.
- Unwrap all the wire from the nails from the previous lesson. Make sure that the ends of all wires are stripped or sanded so the copper wire is exposed.
- Make sure all batteries are new or fully charged. Make sure AA, C, and D batteries are in battery holders.
- Organize materials for the electromagnets so they are easily accessible to

students.
- Make copies of the following duplication masters:
  - *6.a. Client Memo 6* (1 per student)
  - *6.b. Design Ideas Planning Protocol* (1 per student)
  - *6.d. Teacher Observation Protocol: Try* (1 per every 4 teams)
  - *6.e. Evidence-Based Reasoning* (1 per student)
  - *6.h. Design & Justification* (1 per team)

Classroom Instruction (Lesson 6A: Plan)

Introduction

1. **Read the client memo.** Distribute *6.a. Client Memo 6* to the class and have students read it. Discuss the memo and the goals for the lesson.

2. **Identify where they are in the engineering design process. (Plan)** **Ask:** *Which step of the engineering design process will you be working on during the lesson?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot. NOTE: If students begin building, they will move to the "Try" step in the EDP.

3. **Review the criteria and constraints.** Discuss the criteria and constraints of the project, which can be found in *6.a. Client Memo 6.*

4. **Establish a timeline.** Discuss their task for the day and what they need to accomplish by the end of the first class period. Lesson 6A and Lesson 6B should take one day each, so set a goal of completing the plan stage of their design with their team for day one, and a goal of building, testing, and justifying the electromagnet for day two.

Activity

5. **Plan the electromagnetic arm individually.** Individually, students should come up with at least 2 designs for the electromagnet arm using the *6.b. Design Ideas Planning Protocol* handout. Students should justify their choices based on what they learned in Lessons 4 and 5. Have students answer question 1 at the bottom after they have planned individually.

6. **Plan as a team.** Students will work in their teams to consider the plans each individual made and decide on one design for their electromagnet arm as a team. They should again use data from Lessons 4 and 5 and the pros and cons they listed in their *6.b. Design Ideas Planning Protocol* to make decisions on their design. While students plan, circulate throughout the room observing the teams using the *6.d. Teacher Observation Protocol: Try*. Once they have considered all their design options, but before they make their final decision, introduce evidence-based reasoning.

7. **Introduce evidence-based reasoning. Say:** *Now you have at least two different options your teams can use for your design strategy. As a team, you need to decide which plan you would like to use for your initial design. Scientists and engineers work hard to use evidence in making important decisions like this, so as a team you're going to fill out an evidence-based reasoning graphic for the design you decide on.*

Standards Addressed
- Next Generation Science Standards: 3-5-ETS1-3, MS-ETS1-1, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards - Mathematics: MP2, MP3, MP6, 4.MD.B.4, 5.MD.B.2, 6.SP.B.4, 6.SP.B.5.A, 6.SP.B.5.B

Assessments
Pre-Activity Assessment
Responses to "*What step of the design process are you in.*"

Activity Embedded Assessment
"Fist to 5" - check-in with progress on the electromagnet arm design.

Post-Activity Assessment
Provide feedback to *6.b. Design Ideas Planning Protocol* and *6.e. Evidence-Based Reasoning* using the *6.c. Design Ideas Planning Protocol Rubric* and *6.f. EBR Rubric*.

DUPLICATION MASTERS
- 6.a. Client Memo 6
- 6.b. Design Ideas Planning Protocol
- 6.e. Evidence-Based Reasoning
- 6.h. Design & Justification

EDUCATOR RESOURCES
- 6.c. Design Ideas Planning Protocol Rubric
- 6.d. Teacher Observation Protocol: Try
- 6.f. EBR Rubric
- 6.g. EBR Instructions

Post an *6.e. Evidence-Based Reasoning* graphic template on the board or on a piece of poster paper and distribute a copy to each student. **Say:** *To help you with your planning, we are going to be using evidence-based reasoning. This means that you will need to support your design ideas with evidence and explanations. We will discuss each of the parts together.* Clarify with students that the *6.g. Evidence-Based Reasoning Instructions* "poster with explanations" will have general explanations and reminders of what kind of information should go in each section. This is different from what the students will write in the templates. They will fill out the boxes with information specific to their engineering design problem.

8. **Review the engineering problem.** Direct students' attention to the "Problem including Criteria and Constraints" section of the *6.e. Evidence-Based Reasoning* graphic. On the poster, write down a general definition of the term problem: the engineering problem the client asked you to solve. Instruct students to write a summary of their engineering problem in this section, leaving room for criteria and constraints.

9. **Review the criteria and constraints of the problem. Ask:** *Can anyone remind me what the words "criteria" and "constraints" mean?* Criteria are the requirements, or goals, of the designed solutions. Constraints are things that limit design possibilities. Write these definitions on the *6.g. Evidence-Based Reasoning Instructions* poster. Refer students back to their lists of criteria and constraints from their Define the Problem notes. **Ask:** *What are some of the criteria and constraints of our engineering problem?* Discuss the criteria and constraints of the problem, and have students write them in the "Problem including Criteria and Constraints" section of the *6.e. Evidence-Based Reasoning* graphic.

10. **Introduce the concept of simplifying assumptions. Say:** *Engineers usually don't deal with every single aspect of a problem at once because that makes the problem too difficult to solve. Instead, they make a complex problem simpler, sometimes by ignoring some of the details of the problem and sometimes by pretending certain things are true about the problem when they actually aren't.* Give an example from this problem or another. Write "ways to make a complex problem simpler" in the "Simplifying Assumptions (if any)" section of the *6.g. Evidence-Based Reasoning Instructions* poster with explanations. **Ask:** *What are some parts of our engineering problem that we can make simpler?* This may be a difficult concept for students, so providing an example or two may be necessary.
    - Simplifying assumptions (things to ignore): aesthetics/appearance, durability (how well it withstands wear and damage).
    - Simplifying assumptions (assume certain things are true when they aren't): materials used in classroom are similar to those the client has.

11. **Explain what information goes in each of the remaining sections.** Have students guess at what kind of information they think should go in the "Plan," "Data/Evidence," and "Explanation, Justification, Reasoning" sections of the *6.e. Evidence-Based Reasoning* graphic. Write down relevant student suggestions in the appropriate section of the *6.g. Evidence Based-Reasoning Instructions* poster. This could include:

- **Design Idea:** Description of the design idea; drawings of the design idea, possibly with different views (e.g., top view, side view); dimensions/sizes/angles; materials in the design idea labeled to show where they are used; interesting features of the design idea.
- **Data/Evidence:** Observations and data that show why you think your design will work. Examples: data from the labs and simulations.
- **Justification:** Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

12. **Choose a design and justify it.** Have students return to their design ideas. Have them make a final decision about which design they will choose. Once they have made a choice, they will fill in the remainder of the *6.e. Evidence-Based Reasoning* graphic. Before they do this, however, to scaffold evidence and justification, have them fill out *6.h. Design & Justification*. Once they have filled this out, they should use this information to help complete the *6.e. Evidence-Based Reasoning* graphic.

13. **Draw a sketch.** Once teams have come to a decision on one design and done their justification, students will draw a detailed and labeled sketch of their design. After they have filled out the *6.e. Evidence-Based Reasoning* graphic as a team, have students individually answer question 2 on the *6.b. Design Ideas Planning Protocol* handout. NOTE: All information from the *6.h. Design & Justification* should be included in the EBR graphic. You may (optionally) choose to skip handout *6.h. Design & Justification* and go directly to the EBR graphic to shorten the process. If you choose this option, however, make sure that students include evidence and justification for all pieces of the design listed in handout *6.h. Design & Justification*.

14. **(Optional) Begin building.** If teams finish planning before the end of class, you may choose to allow them to begin building their prototype.

Closure

15. **Check in on progress.** Ask students to show a “Fist to 5” in response to how far along they are in their design – again, 0 is haven’t started, 3 is part way done, and 5 is completely done.

16. **Review the timeline.** Remind students of the goals for finishing the planning, building, and testing portions of the unit.

Name________________________________ Date___________ Period _____

6.a. Client Memo 6

GALACTIC GAMES
4 Milky Way
Earth, Orbiting the Sun
24365

Memo

To: engr.teams@myschool.org

From: orion.nova@galacticgames.com

CC: halley.comet@galacticgames.com, apollo.eos@galacticgames.com, luna.titania@galacticgames.com

Re: Plan and Design

Wow! Fantastic work. We are getting very close to our deadline. We will need each team to come up with a design plan and build a prototype of your electromagnet arm by the end of the next work day. Along with a detailed picture of your design, you need to provide a justification for each decision you make. Please remember to adhere to the following criteria and constraints from our previous communications:

Criteria:
- The prototype should be an electromagnet that can be attached to an arm, not a claw.
- You must justify your design decisions using data.
- You must be able to explain your design.

Constraints:
- End users should win some of the time, but not every time.
- You may only use the materials provided.
- You only have one class period to plan your prototype design and one class period to create your prototype.

We have also included a sample toy with a metal "tag" attached for you to use in testing your design.

We're counting on you! Good luck!

Orion

LESSON 6

Name_______________________________ Date___________ Period _____

6.b. Design Ideas Planning Protocol

Directions: Individually, create at least two different design ideas for your electromagnetic arm. If you want to do more than two, work on the back of this sheet or on another page in your notebook.

Design Idea	Why do you think it will work?
Idea #1	
Idea #2	

Answer the following question about your own design ideas.

1. **What are the pros and cons of each of your solution ideas?**

After your team decides on a solution to try, answer the following question.

2. **Which solution did your team choose and why? Provide evidence for your reason.**

LESSON 6

Student Name________________________________ Date____________ Period _____

6.c. Design Ideas Planning Protocol Rubric

Problem	Question	Learning Objectives	Rubric	
6.b.1	What are the pros and cons of each of your own solution ideas?	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Provided at least 1 pro for each solution generated (as an individual)**
			yes no	**Provided at least 1 con for each solution generated (as an individual)**
6.b.2	Which solution did your team choose and why? Provide evidence for your reason.	Select potential solution through systematic evaluation of various solutions based on the problem.	yes no	**Stated which solution was chosen**
			yes no	**Provided an explanation for why the team chose that solution that was based on evidence**

Notes:

6.d. Teacher Observation Protocol: Try

Team #	All team members are on-task to make/try their solution.	One or more team members are not on-task.	Team has made appropriate progress on their solution.	Team is struggling to make their solution.	Team is making/made a solution directly related to problem.	Team is making/made something unrelated to problem.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about your solution? What are you designing?
2. What were some of the other solution ideas you generated? How well did they address the problem?
3. How did you decide to move forward with this idea? What evidence do you have that your design will solve the problem for the client?

LESSON 6

Name________________________________ Date____________ Period _____

6.e. Evidence-Based Reasoning (1/2)

Problem with Criteria & Constraints • Explain the client's problem that needs a solution and why it is important to solve. • List criteria and constraints you will use to decide if your solution is working.	
Problem: ____ ____ **Criteria:** ____ **Constraints:** ____	
Simplifying Assumptions • List things that might be important but you have decided not to worry about.	
____ ____	
Design Idea #____ • Plan including drawing, labels of materials used, and labels of what each part does.	**Data/Evidence** • List science/mathematics learned and/or results of tests that support your design idea.
	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ______________________

LESSON 6

Name________________________________ Date___________ Period _____

6.e. Evidence-Based Reasoning (2/2)

Justification - Why do you think this design idea will work?

- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Student Name______________________ Date__________ Period _____

6.f. Evidence-Based Reasoning Rubric

Section	Learning Objective	Rubric	
Problem	Explain the problem based on a synthesis of information. Explain why the problem is important to solve based on evidence that is relevant to the problem.	yes no	**Identified problem**
		yes no	**Explained why the problem is important**
Criteria	Explain criteria based on given information.	yes no	**Identified at least 1 criterion**
Constraints	Explain constraints based on information.	yes no	**Identified at least 1 constraint**
Simplifying Assumptions	Explain assumptions they have made in order to make solving the problem more manageable.	yes no	**Identified at least 1 simplifying assumption**
Design Idea	Communicate design idea through drawing, including labels for materials and function of parts.	yes no	**Included drawing to represent design idea**
		yes no	**Included labels of materials**
		yes no	**Included labels of what each part does**
Data/Evidence (List math/science learned and/or results of tests that support your design idea)	Apply evidence gathered from testing to choose solution. Apply math/science concepts to choose solution.	yes no	**Listed at least 1 piece of valid evidence**
		yes no	**Evidence is from mathematics/science they have learned or from the results of the tests**
Justification (Explain how your data/evidence supports your design idea in order to meet criteria/constraints. Why do you think this will work?)	Justify why their design solution is appropriate based on application of core science/ mathematics concepts Justify why their design solution is appropriate based on information obtained in problem scoping.	yes no	**Included explanation of how their data/ evidence supports their design idea**
		yes no	**Explained why this will work**
		yes no	**Explained how design idea will meet criteria/constraints**
Notes:			

6.g. Evidence-Based Reasoning Instructions

Poster with Explanation

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: **the engineering problem the client asked you to solve**

Criteria: **the requirements, or goals, of the designed solutions**

Constraints: **things that limit design possibilities**

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

Ways to make a complex problem simpler

Design Idea #____	**Data/Evidence**
• Plan including drawing, labels of materials used, and labels of what each part does.	• List science/mathematics learned and/or results of tests that support your design idea.
• **Drawings of the design, different views** • **Dimensions (sizes)** • **Description of the design - labels of how different parts function** • **Label materials in design (show where they are used)** • **Interesting features**	**Observations and data that show why you think your design will work** **Examples:** • **Data from science and mathematics lessons, labs, and activities** • **Theoretical science/mathematics that provide reasons for choices they made** • **Total cost of design**

Justification - Why do you think this design idea will work?
- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

Complete sentences that state why it is possible that the design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

6.g. Evidence-Based Reasoning Instructions

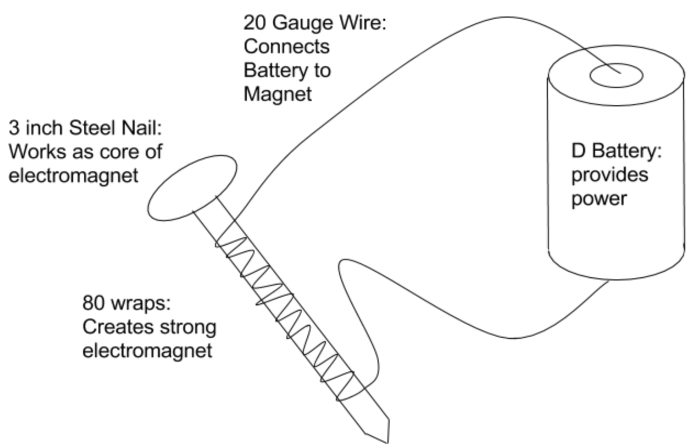
Example Key for Claw Game

Problem with Criteria & Constraints
- Explain the client's problem that needs a solution and why it is important to solve.
- List criteria and constraints you will use to decide if your solution is working.

Problem: Claw games are known to be rigged or unfair, so Galactic Games wants to redesign their claw game, Diggin' For Fools' Gold, to use an electromagnet instead of a claw.
Criteria: The claw should be able to pick up the toys and move them to the shoot, but it should still be a challenge and players should not win every time.
Constraints: The new "claw arm" needs to use an electromagnet. It must be able to pick up the toys provided. It needs to fit inside the claw game.

Simplifying Assumptions
- List things that might be important but you have decided not to worry about.

The rest of the claw game, including the joystick mechanism to move the claw will remain the same, so we won't worry about that.

Design Idea #____	Data/Evidence
• Plan including drawing, labels of materials used, and labels of what each part does.	• List science/mathematics learned and/or results of tests that support your design idea.
	• Electromagnets need a core made out of steel or galvanized steel. EM made from aluminum, stainless steel, plastic or wood, won't work or work as well. • The more coils around the core, the stronger the electromagnet. Specifically 80 coils, lifted about 50 hex nuts. • Thicker wire makes a stronger magnet but is harder to work with. • AA and C batteries don't last very long to power EM

Justification - Why do you think this design idea will work?
- Explain how your data and evidence support your design idea in order to meet criteria/constraints.

We chose to make the core of the electromagnet out of a steel nail because steel works well and is cheaper than galvanized steel. We wanted enough coils to make a strong magnet, but we didn't want it to be so strong that it always catches the toy. 80 coils lifted 50 hex nuts which is about the size of a toy, so we think 80 coils is the right number to grab the toy most of the time but not all of the time. We chose a 3 inch nail because it is long enough to fit all 80 coils, but not too long, and we chose a D battery because the AA and C batteries ran out too quickly.

LESSON 6

Name__________________________________ Date____________ Period ______

6.h. Design & Justification

GALACTIC GAMES

1. Please fill in the table below with the items your team used and explain why you used each item. Use data to explain your decision.

	What did you use?	Why did you use it instead of something else?
Type of Battery		
Number of Batteries		
Gauge of Wire (wire thickness)		
Object the Wire is Wrapped Around		
Number of Wire Coils		
Other		

2. In the space below, please create a DETAILED and LABELED sketch of your electromagnet prototype. All parts of the electromagnet should be clearly labeled.

LESSON 7

Test and Decide

Lesson Objectives

Students will be able to:

- evaluate their role in an academically minded team.
- analyze the data from testing variables of electromagnets to make decisions in their design/solution to the engineering design challenge.
- make a claim supported with evidence.
- evaluate their team's solution to the engineering design challenge.

Time Required

One 50-minute class period

Materials

Per class:

- Engineering Design Process poster
- (50) steel washers
- (1) hot glue gun with hot glue
- (10) duck counters
- (24) D batteries
- (24) C batteries
- (24) AA batteries
- (8) 10 ft insulated copper wire (18, 20, and 22 gauge)
- (24) alligator clips
- (24) battery holders (sizes AA, C, and D)
- (8) 3-1/2 in. steel nail
- (8) 3-1/2 in. stainless steel nail
- (8) 3-1/2 in. aluminum nail
- (8) 3-1/2 in. galvanized steel nail
- (8) 2-1/2 in. steel nail
- (8) 3 in. steel nail
- (8) 4 in. steel nail
- (8) 3-1/2 in. steel bolt (thin)
- (8) 3-1/2 in. steel bolt (thick)
- various other materials from Lessons 4 and 5.

Per student:

- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Lesson Summary

Based on their plan, students will build prototypes and test their design by repeatedly attempting to pick up and transport a small toy with a washer attached from one box to another. After testing their electromagnets, they reflect on their design decisions based on the data they collected.

Background

Teacher Background

SAFETY CONCERN #1: The battery and wires will get hot if left connected. Make sure that students disconnect at least one of the alligator clips from the battery when not testing it. The battery should only be connected with both clips for a few seconds at a time for each test.

SAFETY CONCERN #2: When students connect multiple batteries together, they must be connected in series (not parallel), otherwise they will smoke. Batteries are connected in series when they are connected end to end (+ to -) in one path or loop. Batteries are connected in parallel when the path splits and each battery is part of its own loop.

Before the Activity

- Prepare the testing station. A testing station in this lesson will consist of two containers (shoe boxes or other small containers) and a toy with a washer attached to it. You should prepare one or two testing stations and place them in an easily accessible part of the room. Hot glue a washer to one of the duck counter toys (or other medium sized toys) for each testing station. You may choose to make one for each team to use as they plan and build.
- Make copies of the following duplication master:
  - *7.b. Test Solution Ideas* (1 per student)

Classroom Instruction

Introduction

1. **Review the client memo. Ask:** *What did the client ask us to do in their letter yesterday?*

2. **Review the criteria and constraints.** Discuss the criteria and constraints of the project, which can be found in client memo.

3. **Identify where they are in the engineering design process. (Try and Test) Ask:** *Which step(s) of the engineering design process will you be working on during the lesson?* Have students move the paper clip on their Engineering Design Process slider to the appropriate spot.

4. **Review the timeline.** Remind students of the goals for finishing the try and test phases of the design process.

5. **Plan the "test" for their designs.** Discuss with the students how they will test their designs to know if they meet the criteria. The class (as a whole) may come up with their own plan if deemed appropriate, but a suggested testing plan is described below:
   - **Suggested test of engineering designs.** Place two shoe boxes or

other small boxes on the desk next to each other. Place the toy in one box. Students should attempt to use the electromagnet to pick up the toy, transport the toy to the other box (using their hands to move the magnet—they don't need to design the joystick/motion mechanism), and disconnect the electromagnet to drop it in the other box. Repeat this 10 times.

- **Discuss what counts as success.** The memo from the client states that they don't want the player to win every time. Have a class discussion about the implications of this for the test of their designs. Agree on an ideal number of "wins" out of 10. Six wins out of 10 is a good benchmark, but you may choose to change this.

NOTE: Students may have the toy at their stations to help them as they build their prototypes; however, there should only be one (or perhaps two) official "testing stations." When students believe they are ready, they should bring their prototypes to the testing stations for the test. This will ensure more honest results for the test and also minimize "tinkering."

Activity

6. **Build prototypes.** Have students build their prototypes in their teams. Teams should follow their plans. If they want to make changes to their plans, encourage them to update the justification sheet they completed the day before. While students build, circulate throughout the room observing the teams using the *7.a. Teacher Observation Protocol: Test*.

7. **Test the designs.** When teams are ready, have them bring their prototypes to the testing station to test their designs. They should record their results in their engineering notebooks. **(Optional)** You may prepare a handout for recording data based on the agreed upon testing procedure and distribute this handout. NOTE: If time permits you may offer one round of redesign and retesting at this stage. Review lesson 7 to review how to redesign.

8. **Discuss the designs.** Lead a class discussion of the benefits, similarities, and differences among the designs.

Closure

9. **Reflect on designs.** Students should reflect on their own design, recording in their notebooks how successful they felt it was and what they want to change. Use the prompts from *7.b. Test Solution Ideas* to structure this reflection. Having students reflect on their designs after the class discussion allows students to hear other ideas and gives more processing time before deciding on the changes to their design.

Key Terms

constraint, criteria, prototype

Standards Addressed

- Next Generation Science Standards: 3-5-ETS1-3, MS-ETS1-1, MS-ETS1-3, MS-ETS1-4
- Common Core State Standards - Mathematics: MP2, MP3, MP6, 4.MD.B.4, 5.MD.B.2, 6.SP.B.4, 6.SP.B.5.A, 6.SP.B.5.B

Assessments

Pre-Activity Assessment
Responses to "*What step of the design process are you in.*"

Activity Embedded Assessment
Use the *7.a. Teacher Observation Protocol: Test* to evaluate students as they build and test their prototypes.

Post-Activity Assessment
Provide feedback to students' notebooks using the *7.c. Test Solution Ideas Rubric.*

DUPLICATION MASTERS

- 7.b. Test Solution Ideas

EDUCATOR RESOURCES

- 7.a. Teacher Observation Protocol: Test
- 7.c. Test Solution Ideas Rubric

LESSON 7

Name________________________________ Date___________ Period _____

7.b. Test Solution Ideas (1/2)

Directions: Please answer the following questions about what you learned from testing.

1. **What are the results of your test(s)?**

2. **What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.**

   My response:

   Team response:

3. **What changes will you make to improve your solution based on the results of your tests?**

   My response:

   Team response:

4. **Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.**

   My response:

   Team response:

LESSON 7

Name__________________________________ Date____________ Period _____

7.b. Test Solution Ideas (2/2)

5. In what ways does your solution meet the criteria and constraints of the problem?

My response:

Team response:

6. In what ways does your solution not yet meet the criteria and constraints of the problem?

My response:

Team response:

7.a. Teacher Observation Protocol: Test

Team #	All team members are on-task to test solution.	One or more team members are not on-task.	Team has made appropriate progress on testing and analysis.	Team is struggling to test or analyze their solution.	Team has identified how to improve solution.	Team is struggling to consider improved performance.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. What did you find out from testing?
2. How did you interpret the findings from your tests? What do you think the results mean?
3. How did you decide what could improve your solution's performance?

LESSON 7

Student Name______________________________ Date__________ Period _____

7.c. Test Solution Ideas Rubric

Problem	Question	Learning Objectives	Rubric	
7.b.1	What were the results of your test(s)?	Analyze test results.	yes no	**Listed specific results of tests**
7.b.2-4	2. What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work. 3. What changes will you make to your solution based on the results of your tests? 4. Why will you make those changes? Think about the results of your tests and the mathematics and science you have learned.	Analyze test results. Apply evidence gathered through test analysis to improve the performance of chosen solution. Apply evidence gathered from testing to choose solution. Apply mathematics/science concepts to inform redesign.	yes no	**Explained advantages of solution found in tests**
			yes no	**Explained drawbacks of solution found in tests**
			yes no	**Listed planned improvements**
			yes no	**Explained rationale for improvements based on test results**
			yes no	**Explained rationale for improvements based on correct understanding of mathematics/ science**
7.b.5	In what ways does your solution meet criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Compared their solution to specified criteria and constraints**
7.b.6	In what ways does your solution not yet meet the criteria and constraints of the problem?	Evaluate the alignment between their proposed solution and the problem.	yes no	**Contrasted their solution to specified criteria and constraints**

Notes:

LESSON 8

Redesign: Plan, Try

Lesson Objectives

Students will be able to:

- evaluate their team's solution to the engineering design challenge.
- to revise their design/solution to the engineering design challenge.

Time Required

one 50-minute class period

Materials

Per class:

- EDP poster
- (50) steel washers
- (1) hot glue gun and hot glue sticks
- (10) duck counters
- (10) rubber duckies
- (10) bear counters
- (10) bouncy balls
- (10) insect toys
- (10) toy cars
- (24) D batteries
- (24) C batteries
- (24) AA batteries
- (8) 10 ft insulated copper wire (18, 20, and 22 gauge)
- (24) alligator clips
- (24) battery holders (sizes AA, C, and D)
- (8) 3-1/2 in. steel nail
- (8) 3-1/2 in. stainless steel nail
- (8) 3-1/2 in. aluminum nail
- (8) 3-1/2 in. galvanized steel nail
- (8) 2-1/2 in. steel nail
- (8) 3 in. steel nail
- (8) 4 in. steel nail
- (8) 3-1/2 in. steel bolt (thin)
- (8) 3-1/2 in. steel bolt (thick)
- various other materials from Lessons 4 and 5.

Per student:

- (1) engineering notebook
- (1) EDP slider
- (2) different color writing utensils

Lesson Summary

After the initial design and test with one toy, the client asks the students to redesign and retest their new designs, but this time with several different toys of different sizes, more like an actual claw game. Students use what they learned while testing their original designs to make a new plan for their electromagnetic claw arm, and they will justify those decisions. Time permitting, students will begin testing their new designs by moving toys with a variety of different sizes and weights from one container to another

Background

Teacher Background

Learning from failure: One of the most important aspects of engineering is learning from failure. Engineers often purposefully test models and prototypes until failure in order to better understand the limits of their designs. The engineers then use what they learned from this failure to redesign. Thus, in the engineering design process, it is important to continue beyond the first design cycle.

Redesign: After analyzing and evaluating their first prototype, students will begin to identify potential problems in the design, construction, organization, or cost of the original. At this point, some students will want to leap into a new design, others will insist on the success of their first prototype, while others may want to give up. The teacher can be a key factor in encouraging and guiding students through this transitional time. Because some students may be overly eager and want to skip the plan step of redesign, remind them of the importance of thinking through a design and creating written plans. For teams who are satisfied with their initial design's performance, encourage them to create a design that improves performance. For all teams, especially those who may want to give up, remind them that failing and then redesign is a key part of engineering and what professional engineers do. This is the stage in which students' understanding and skills are deepened and strengthened as they struggle with challenges and decisions. Learning from failure is not just an important skill for engineering, but it is also an important life skill. For redesign, encourage student teams that did not meet the main criteria to focus on meeting those criteria in their redesign. For teams that did meet the main criteria, encourage them to improve their design. Additionally, teams can think about other features that came up during defining the problem or testing the solution.

SAFETY CONCERN #1: The battery and wires will get hot if left connected. Make sure that students disconnect at least one of the alligator clips from the battery when not testing it. The battery should only be connected with both clips for a few seconds at a time for each test.

SAFETY CONCERN #2: When students connect multiple batteries together, they must be connected in series (not parallel), otherwise they will smoke. Batteries are connected in series when they are connected end to end (+ to -) in one path or loop. Batteries are connected in parallel when the path splits and each battery is part of its own loop.

Redesign: Plan, Try

Before the Activity

- Prepare testing stations. For this lesson, the testing station again consists of two small containers (i.e. shoeboxes), but this time you will need many toys of various sizes. Hot glue washers to all the toys you plan to use for the testing stations. An assortment consisting of 5 each of rubber duckies, bear counters, duck counters, bouncy balls, toy cars, and glow in the dark insects should be sufficient.
- Make sure that the batteries are completely charged. Electromagnets use up batteries faster than many other applications.
- Be sure the ends of the copper wire are sanded or stripped so they make a good connection.
- Make copies of the following duplication master:
    - *8.a. Client Memo 7* (1 per student)

Classroom Instruction

Introduction

1. **Read the memo from the client.** Distribute *8.a. Client Memo 7* and have students read the memo from the client that explains their next steps. Discuss the memo and the goals for the day.

2. **Discuss the new design test.** The test at this stage will be very similar to the test in the previous lesson. Students should repeatedly attempt to move a toy from one box to another with their magnets. In this test, however, instead of just having one toy, the box will contain many toys, some of each of three different sizes. Have a class discussion on how the class will carry out this test and agree on a procedure and what counts as success. Here are some suggestions:
    - Try all three sizes 10 times (each) for a total of 30 trials. If the magnet is successful 12 to 18 times it meets the criteria. Students can then compare the success rates for the different sized toys.
    - Try all three sizes 3 or 4 times (each) for a total of 9 or 12 trials. If the magnet is successful 4 to 7 times it meets the criteria. Students can then compare the success rates for the different sized toys.
    - Do 10 trials, choosing a variety of sizes at the discretion of the individual teams and recording the size they tried for. If the magnet is successful 4 to 6 times it meets the criteria. Students can then compare the success rates for the different sized toys.

3. **Identify where they are in the engineering design process. (Decide) Ask:** *Which step of the engineering design process will you be working on during the lesson?* Students may recognize parts of other steps in the engineering design process, and that is okay as well. Have students move the paper clip on their engineering design process slider to the appropriate spot.

Activity

4. **Plan their redesign.** Based on the performance of their electromagnet, students will work with their team to redesign their electromagnet arm so that it works with the three different toys provided. Teams should have access to one of each of the different sized toys as they plan.

Standards Addressed

- Next Generation Science Standards: 3-5-ETS1-2, 3-5-ETS1-3, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3 , MS-ETS1-4
- Common Core State Standards - Mathematics: MP1, MP2, MP3, 6.SP.B.5.A

Key Terms

constraint, criteria, redesign

Assessments

Pre-Activity Assessment
Responses to "*What step of the design process are you in.*"

Activity Embedded Assessment
Justification on design decisions, "fist to 5" check in where students respond to how far along they are in their design.

Post-Activity Assessment
"Fist to 5" check-in with students to gauge their redesign progress, 0 is haven't started, 3 is part way done, and 5 is completely done.

DUPLICATION MASTERS

- 8.a. Client Memo 7

EDUCATOR RESOURCES

- 8.b. Teacher Observation Protocol: Redesign

Redesign: Plan, Try

5. **Justify their design decisions.** After students have decided on a plan for the redesign, have them respond to the following prompts in their notebooks:
   - What did you change about your design?
   - Why did you make that change?

6. **Build the new prototype.** Have students assemble their new prototypes based on their redesign plans. While students build, circulate throughout the room observing the teams using *8.b. Teacher Observation Protocol: Redesign.*

7. **(Optional) Begin testing.** If time permits, you may allow teams to begin testing their redesigns before the end of class. While students test, circulate throughout the room observing the teams using *8.b. Teacher Observation Protocol: Redesign.*

Closure

8. **Check for progress.** "Fist to 5" check-in with students to gauge their redesign progress, 0 is haven't started, 3 is part way done, and 5 is completely done.

Redesign: Plan, Try

Name______________________________ Date__________ Period _____

8.a. Client Memo 7

GALACTIC GAMES
4 Milky Way
Earth, Orbiting the Sun
24365

Memo

To: engr.teams@myschool.org

From: halley.comet@galacticgames.com

CC: luna.titania@galacticgames.com, apollo.eos@galacticgames.com, orion.nova@galacticgames.com

Re: Final Design Due

Thank you for your hard work on your initial designs. We were very impressed with what you came up with, but we'd like a slightly more realistic test. This time, we've sent along a whole set of toys. You'll notice that there are three sizes of toys—small, medium, and large. For your test, you should try to pick up different sized toys and keep track of which toys you were able to pick up and which toys fell. Before you test, please redesign your electromagnetic arms and make any changes necessary to meet all constraints and criteria. We'd like to see the toys picked up and moved 4-6 times out of 10 tries. We'd also like players to win small toys more often than larger toys. If your redesigned prototype does not meet that criteria, you must redesign it again and update your justification.

Once your team has your final design, prepare a poster that explains your design, why you made it the way you did, and how successful you think it is. Your teacher has specific details for you on how we want you to make your posters. Please get this to us by the end of your next workday.

Thanks again for your great work,

Halley

8.b. Teacher Observation Protocol: Redesign

Team #	All team members are on-task to retest their solution.	One or more team members are not on-task.	Team has attempted to improve the performance of their solution.	Unclear what has been done to improve their solution.	Notes

Optional Question Prompts:

NOTE: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

1. Can you tell me about how you are working to improve your solution?
2. What were some of the other solution improvement ideas you generated?
3. How did you decide to move forward with this idea? What evidence do you have that your improved design will solve the problem for the client?

LESSON 9

Redesign: Decide, Share

Lesson Objectives

Students will be able to:

- create a presentation to effectively address their audience and portray their ideas.
- make a claim, supported with evidence.

Time Required

One 50-minute time period

Materials

Per team:

- (1) poster or chart paper
- (1) pack of markers

Per student:

- (1) engineering notebook
- (1) Engineering Design Process slider
- (2) different color writing utensils

Standards Addressed

- Next Generation Science Standards: 3-5-ETS1-2, 3-5-ETS1-3, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3 , MS-ETS1-4
- Common Core State Standards - Mathematics: MP1, MP2, MP3, 6.SP.B.5.A

Lesson Summary

Once students have finished testing their redesigned claw arms, the students present their best design to the client through a poster presentation. The poster describes the results of the tests, as well as the reasoning behind their design choices.

Background

Teacher Background

Communication of final designs is a key point in the engineering design process. Specifically, it provides students a chance to demonstrate how their understanding of the science behind electromagnets informed their decisions about their designs. It also provides them with valuable opportunities to develop communication skills required both in engineering and in many other careers and activities.

Before the Activity

- Prepare testing stations. For this lesson, the testing station again consists of two small containers (i.e. shoeboxes), but this time you will need many toys of various sizes. Hot glue washers to all the toys you plan to use for the testing stations. An assortment consisting of 5 each of rubber duckies, bear counters, duck counters, bouncy balls, toy cars, and glow in the dark insects should be sufficient.
- Make copies of the following duplication masters:
  - *8.a. Client Memo 7* (1 per student)
  - *9.a. Final Presentation Rubric* (1 per student)
  - *9.b.. Redesign Evaluation* (1 per student)
  - *9.d. Unit Reflection* (1 per student)

Classroom Instruction

Introduction

1. **Review the client memo and goals for the day.** Have students read *8.a. Client Memo 7* and discuss what the client has asked for and what they are working on.

2. **Review testing procedure.** Remind students about the testing procedure they agreed upon on the previous day.

3. **Discuss final presentations.** Explain that students will want to use the presentation to convince the client that their design is a good design that meets the criteria and constraints. Lead a discussion of what they should include to be convincing. Show students the *9.a. Final Presentation Rubric* and discuss the requirements with them.

Activity

4. **Test their redesigned prototypes.** Allow students to continue working on building their prototypes. As they finish, students should bring their prototypes to the testing stations to test their designs. Make sure that they record the data from their tests in their engineering notebooks. Have students fill out the *9.b. Redesign Evaluation* and add that to their notebooks.

5. **Communicate their designs.** Have students prepare a poster describing their design (both in words and with a picture), why they chose to build it that way, the results of the test, and the strengths and weaknesses of the design. Have students prepare their poster in the format of an Evidence-Based Reasoning graphic. Students should use evidence from Lessons 4 and 5 as well as from the tests they just conducted.

6. **Share the designs.** Once all teams have finished their posters, students will share their designs and justifications with the class by doing short presentations or a gallery walk. While students do the gallery walk or listen to their classmates' presentations, they should have their notebook with them to record the team names and one benefit of that team's design in a T-chart. Possible benefits include being easy to assemble, using fewer materials, producing good test results, etc. **(Optional)** If the appropriate technology is available, you may choose to have students make short video presentations to "send to the client." In this case, make sure that all information required in the EBR graphic poster is included in the video.

Closure

7. **Reflect on engineering design process.** Have students respond to the prompts in *9.d. Unit Reflection*.

8. **Provide feedback from the client.** At the beginning of the next class period, provide feedback from the client. Let them know that the client was very thankful for their hard work, and give specific examples of solutions that met the criteria and constraints as well as teams that justified their designs and the choices they made well. You may decide whether to prepare one final client memo or give this feedback verbally.

Assessments

Pre-Activity Assessment
Responses to "*What step of the design process are you in.*"

Activity Embedded Assessment
9.a. Final Presentation Rubric.

Post-Activity Assessment
Design presentations. Provide feedback to students in their notebooks using the *9.c. Redesign Evaluation Rubric* and *9.e. Unit Reflection Rubric.*

DUPLICATION MASTERS

- 9.a. Final Presentation Rubric
- 9.b. Redesign Evaluation
- 9.d. Unit Reflection

EDUCATOR RESOURCES

- 9.c. Redesign Evaluation Rubric
- 9.e. Unit Reflection Rubric

LESSON 9

Name________________________________ Date____________ Period _____

9.a. Final Presentation Rubric

	1	2	3	4
Required Parts: Problem Statement, Simplifying Assumptions, Description of Design, Drawing, Data/Evidence, Explanation, Justification & Reasoning	More than three required parts are missing	Two or three required parts are missing	One required part is missing	All required parts are present
Does the electromagnet meet the criteria?	Electromagnet never picks up the toy	Electromagnet picks up the toy EVERY time	Electromagnet picks up the toy 8 or more times OR 3 or fewer times	Electromagnet picks up the toy some of the time (at least 4), but not all of the time (no more than 7 times).
Description of Electromagnet	Description includes 3 or fewer of the following: number of coils, wire gauge, number of batteries, size of battery, number of alligator clips, core material	Description includes 4 of the following: number of coils, wire gauge, number of batteries, size of battery, number of alligator clips, core material	Description includes 5 of the following: number of coils, wire gauge, number of batteries, size of battery, number of alligator clips, core material	Description includes all of the following: number of coils, wire gauge, number of batteries, size of battery, number of alligator clips, core material
Data/Evidence	No data or evidence is given	Some data are given, but data are not recorded or displayed clearly or correctly	Some data are given, which are presented clearly and correctly, but more data are needed	All data needed to justify decisions is presented clearly and correctly
Justification of Electromagnet Design	No justification given for the design	Justifications are unrelated to both the design and the evidence	Justifications are related to the design, but do not rely on the data or evidence provided	Justifications clearly show how the data and evidence were used to make design decisions
Teamwork	Some members did not contribute at all to the engineering design process or presentation	All members contributed to the design and presentation, but not all members participated equally	All members contributed equally to the engineering design OR the presentation, but not both	All members contribute equally to both the engineering design and the presentation
Poster	The poster is messy, disorganized, and hard to read	The poster is organized, but still messy and hard to read	The poster is well organized and easy to read	The poster is well organized, easy to read, and is decorated in a way that makes the main ideas stand out

Total points: ______/28

LESSON 9

Name____________________________________ Date____________ Period ______

9.b. Redesign Evaluation

Directions: Please answer the following questions about the overall quality of your solution.

1. What are the results of your tests?

My response:

Team response:

2. Did your redesign improve your solution? Why or why not?

My response:

Team response:

3. If you could do another redesign, how would you try to improve your solution?

My response:

Team response:

LESSON 9

Student Name______________________________ Date__________ Period _____

9.c. Redesign Evaluation Rubric

Problem	Question	Learning Objectives	Rubric	
9.b.1	What were the results of your test(s)?	Test improved solution and reflect on test results.	yes no	**Listed specific results of tests**
9.b.2	Did your redesign improve your solution? Why or why not?	Test improved solution and reflect on test results.	yes no	**Answered question and provided reasons for improvement or no improvement.**
9.b.3	If you could do another redesign, how would you try to improve your solution?	Test improved solution and reflect on test results.	yes no	**Listed planned improvements**

Notes:

LESSON 9

Name______________________________________ Date____________ Period _____

9.d. Unit Reflection

Directions: First, **on your own,** answer each of the following questions beside the "My Response" space. Then, in your teams, each person is to share their response and discuss. In the space, "Team Response" **write your revised answer** to the question, based on discussion with your team. You may use a different color writing utensil to distinguish your answer and how it changed after talking with teammates.

1. **How has your <u>understanding of the problem</u> changed during the design process?**
   - Look back to the places where you defined the problem in your Engineering Notebook.
   - Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

   My response:

   Team response:

2. **How has your <u>understanding of how to design a solution</u> changed during the design process?**
   - Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem.
   - Think about what you did and how you made decisions to solve the problem.

   My response:

   Team response:

Student Name______________________ Date__________ Period _____

9.e. Unit Reflection Rubric

Problem	Question	Learning Objectives	Rubric	
9.d.1	How has your understanding of the problem changed during the design process? • Look back to the places where you defined the problem in your engineering notebook. • Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.	Communicate how their understanding of the problem deepened through the design process.	yes no	**Explained how their understanding of the problem has changed**
			yes no	**Included at least 1 of client needs, criteria/constraints, and science/mathematics in their explanation**
9.d.2	How has your understanding of how to design a solution changed during the design process? • Look back in your engineering notebook to see how you developed your solution throughout solving the problem. • Think about what you did and how you made decisions to solve the problem.	Communicate how their understanding of how to design solutions changed through the design process.	yes no	**Explained how their understanding of the how to design a solution has changed**
			yes no	**Included at least 1 example from their experience or how they made decisions in their explanation**

Notes:

Notebook Prompts and Titles

Teacher Directions:

If you prefer to have students write the answers to prompts right in their notebooks (rather than on the handouts and then adhere them to the notebooks), you should have the students put the bold title for each prompt and then answer the question that follows. The format for each will be as follows:

Prompt title:
Question to answer

Have students answer each set of questions as they appear in the curriculum. If any questions are included in the curriculum, but not included here, you may determine the title for the prompt.

Problem Scoping Lessons - Define and Learn

Section 1:

Engineers:
What do engineers do?

Solve Problems:
How do engineers solve problems?

Section 2:

Questions for client:
What are at least 3 questions that you want to ask the client that will help you understand the problem better? Make sure to ask about all important aspects of the problem.

Section 3:

Client:
Who is the client?

Problem:

What is the client's problem that needs a solution? Explain why this is important to solve. Use information from your client to support your reasons.

End-users:
Who are the end-users?

Criteria:
What will make the solution effective (criteria)? Use detailed information you have from the client.

Constraints:
What will limit how you can solve the problem (constraints)? Use detailed information you have from the client.

What we need to learn:
Think about the problem of claw games that appear rigged. In terms of using magnets to pick up the toys, what are at least 2 things you need to learn in order to design an electromagnetic claw arm for the claw game? Make sure to consider all important aspects of the problem. Be specific.

Notebook Prompts and Titles

Generate Ideas/Plan Lessons

Section 1:

EBR Graphics can just be drawn in notebooks.

Section 2:

Have students answer the following after EBR graphics are complete.

Pros and Cons:
What are the pros and cons of each of your solution ideas?

Why we chose our solution:
Which solution did your team choose and why? Provide evidence for your reason.

Test Solution Idea(s) Lessons

Section 1:

Ask students to complete after they have run their tests.

Test results:
What were the results of your test(s)?

Learned from test results:
What have you learned about the performance of your solution from your test results? Explain both the things that worked and did not work.

Changes from test results:
What changes will you make to your solution based on the results of your tests?

Reason for changes:
Why will you make those changes? Think about the results of your test and the science and mathematics you have learned.

Section 2:

Section 2 questions should come after the students have run their tests and have had an opportunity to answer Section 1 questions.

How solution meets criteria and constraints:
In what ways does your solution meet the criteria and constraints of the problem?

How solution does not yet meet criteria and constraints:
In what ways does your solution not yet meet the criteria and constraints of the problem?

Notebook Prompts and Titles

Redesign Lessons

Ask students to complete after they have run their redesign tests.

Test results:
What were the results of your test(s)?

Improvement?:
Did your redesign improve your solution? Why or why not?

Next ideas for improvement:
If you could do another redesign, how would you try to improve your solution?

Final Solution Lessons

Section 1:

Students use evidence-based reasoning in reporting their final solution to the client. This can happen through use of the EBR graphic as part of their memo or presentation, or you can have the students include the aspects of the EBR graphic (without the graphic itself) in the memo or the presentation.

Section 2:

These questions should be completed after presenting the solution to the client and the entire design challenge is complete.

Understanding of the problem:
How has your <u>understanding of the problem</u> changed during the design process?

- Look back to the places where you defined the problem in your engineering notebook.
- Think about client needs, criteria/constraints, and science/mathematics needed to solve the problem.

Understanding of designing a solution:
How has your <u>understanding of how to design a solution</u> changed during the design process?

- Look back in your engineering notebook to see how you developed your solution throughout solving the problem.
- Think about what you did and how you made decisions to solve the problem.

Generate Ideas/Plan Lessons